A REPORT ON THE BUILDING AND ORNAMENTAL

STONES OF GEORGIA

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By

George P. Woollard

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PREFACE

This report has been written with the ultimate aim of being published in whole or in part by the State Department of Geology. Although there are in existence state bulletins describing and locating the big majority of the building and ornamental stones of the state, there is little or no information available as to the physical characteristics of these stones. At the suggestion of Dr. Geffory Crickmay, Assistant State Geologist, and with the approval of the Late Dr. S. W. McCallie, State Geologist, and Prof. C. D. Gibson of the Geology Department of Georgia Tech, the author began assembling material and obtaining specimen for test purposes in the summer of 1932 for the preparation of a report relating particularly to the strength and durability of those stones found in Georgia that are used for building purposes.

In conducting the experimental work of this report the material had to be obtained wherever possible. Many of the quarries were not operating. Of those quarries that were in operation it was found difficult to obtain specimen that could be used for tests. This was due as much to lack of equipment on the part of some of the quarrymen as to lack of interest on the part of others. As there was no fund for conducting any of this work, the collecting of suitable specimen from the quarries and various stone yards as well as the making of test specimen was at the author's expense. In a work of this type where so many specimen are required on which tests are made to furnish the basis for conclusions, the cost of having parties equipped to make the test specimen was found to be prohibitive. The result was that the specimen had to be worked out with whatever equipment that could be obtained. Through the cooperation of the Department of Civil engineering and the Department of Geology along with the aid of what was then the Department of Experimental engineering at Georgia Tech a limited number of test specimen of the various stones collected was worked out. The equipment was entirely unorthodox and not intended for the class of service for which it was used. The result was that the entire summer of 1933 was consumed in making these test specimen from the material which had been gathered during the preceding year.

Wherever possible specifications as laid down by the American Society of Testing Materials were followed in conducting tests. Where no set method of test existed, the author was guided by previous work done by other investigators along the same line. Some radical changes in test methods were made in regard to frost action and methods of determining the modulus of elasticity which have since been justified by the work of D. W. Kessler, Research Associate, and W. H. Sligh, Associate Physicist, of the Department of Commerce, Bureau of Standards, in their work on the physical properties of commercial Limestone.

In addition to the departments listed above who assisted in the work of preparing specimen, the author is indebted to the State Geology Department for its aid in obtaining specimen and the use of its library; the Georgia Marble Company who furnished specimen of the marbles tested; the Southeastern Granite Corporation of Elberton and the Capital Stone Company of Atlanta for the variety of granites tested; the Mechanical Engineering Department of Tech for the use of testing equipment; the Bureau of Standards of the Department of Commerce for suggestions in conducting some of the tests where existing methods were of dubious value.

OBJECTIVE OUTLINE

As outlined, this report is to cover only those stones found in the State of Georgia of commercial importance. The general term stone will have to be qualified as pertaining only to that stone used in building construction rather than including that quarried for road work, cement manufacture, fluxes, gems, and as ores of various minerals.

Under Part I will be discussed the different types of rock found in Georgia; their mode of origin, mineral constituents and the minerals themselves so that a better understanding of rocks and their different characteristics can be had.

Under Part II the general geology and physiography of the state will be discussed so that a better idea can be had as to what rocks are dominant in the state, and some idea can be obtained as to their distribution and extent.

In Part III will be discussed the various tests applied to Georgia Building Stones along with the results obtained and conclusions based on these results.

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A REPORT ON THE BUILDING AND ORNAMENTAL STONES OF GEORGIA

BY GEO. P. WOOLLARD

PART I

INTRODUCTION

Almost any variety of stone can be used for building purposes, but economic considerations such as accessibility and ease of quarrying, in general are the controlling factors as to whether a stone is used or not. Any attempt to render a complete report on all the stones in an area as large as the state of Georgia would involve a study of rocks rather than a comprehensive report on stones economically usable. In this report only those stones representative of definite areas now being quarried will be considered. No attempt will be made to include stones other than these.

All building stones may be divided up into four groups:

1. Granite and its allies
2. Sandstone and similar rocks
3. Limestone and similar rocks
4. Slates

These constitute the main rocks used for building purposes. On account of exceptional specimen these rocks may grade into ornamental stone, and likewise some ornamental stones may grade into gem stones. Hence it is seen that there is no definite line of demarcation between a building stone and an ornamental stone. Parks[1] lists the following as being both ornamental and building stones:

Handsome varieties of Granite and other Igneous rocks
The iridescent Feldspars
Sodalite and sodalite bearing rock
Serpentine and Verde Antique
Handsome varieties of Conglomerate and Breccia
Fossil Limestone, Marble, Mexican Onyx
Vein Stuff and varieties of silica, as, Agate, and Amethyst
Varieties of Gypsum

Stones are all the products of natural processes, and by studying their mode of origin it is possible to explain their grain structure, composition, and as a corollary, their strength, weathering properties, and economic uses.

The first group of rocks mentioned was Granite and its allies. These rocks are known as Igneous, for they have resulted from consolidation of molten material from the interior of the earth.

1. Report on Building and Ornamental Stones of Canada, Parks; p. 4

The second and third groups may be mentioned together; that is, the Sandstones and Limestones. These rocks are known as Sedimentary. They are composed of materials laid down in water, and are derived from the weathering of older rocks in the case of sandstone, and from the calcareous body parts and shells of marine life in the case of Limestones. With these rocks might also be mentioned Conglomerate and Gypsum as they are both of sedimentary origin.

The fourth group, Slates, belongs to the Metamorphic rocks. This group includes all rocks, regardless of primary origin, that have been subjected to severe alteration since their formation, the alteration being both chemical and physical. A gneiss is an altered igneous rock; marble is an altered limestone; and slate is altered shale. Shale is a sedimentary mud or very fine-grained sandstone.

There is another group which includes all those materials which fill cavities and veins in older rocks as agate, amethyst, cave onyx, etc. However, this last group has very little use as building stones, and limited use as ornamental stones.

In addition to considering the manner of origin of rock it is necessary also to consider the mineral constituents. Each mineral has different physical properties, and the percentage of each mineral present in a rock will largely determine the physical properties of the rock itself. As minerals of igneous origin are associated with igneous rocks it might be well to consider the minerals in groups according to the rock groups previously considered.

There are two methods by which solidification of a molten mass can take place; either by suspended animation of flow due to a decrease of molecular activity as in the case of glass which is essentially a liquid at rest and which is homogenous throughout, or by molecular rearrangement in which is had crystallization, or the seggregating of minerals according to the laws of crystallography. Rocks as a result vary in character as to whether they are predominantly glass or minerals. This is determined almost entirely by the method of cooling. A molten mass suddenly cooled, as lava shot forth from a volcano, has a strong tendency to be glassy; while a magma slowly cooled deep within the earth's crust is composed almost entirely of crystalline minerals on solidification.

There are two sets of causes that determine the physical properties of igneous rocks; first, the mineral composition, and second, the rock structure. As has already been pointed out, the mineral content largely determines the character of the rock. In igneous rocks there are seven outstanding minerals which have to be considered. Each mineral has a defimite chemical composition. For each mineral there is also a definite crystal shape due to molecular arrangement, and each mineral has its own individual characteristics as to cleavage, hardness, luster, color, blow pipe reactions, etc. The minerals to be considered in connection with igneous rocks can be divided into two classes:

1. The essential minerals forming the bulk of the rock

2. The secondary minerals, not essential and occurring in small and varying proportions.

IGNEOUS ROCKS

Quartz, one of the commonest of the earth's minerals is the crystallized form of silicon dioxide, SiO_2. It forms the bulk of all sands and their derivatives. It has a hardness of 7 according to Moh's Scale of Hardness, and will readily cut steel. Normally it is colorless but it is found in practically all colors. It can be distinguished from Feldspar which it resembles by its conchoidal fracture. It is found in all igneous rocks especially in granite and porphry, and is the mineral which gives these rocks their hardness and strength. An excess makes quarrying and cutting costs prohibitive on account of excessive hardness.

Feldspar is really a group name as there are two main groups of Feldspars, the potash or Orthoclase Feldspar, $K\,Al\,Si_3O_8$; and the soda-lime or Plagioclase Feldspar, $Na\,Al\,Si_3O_8$. Feldspar has a hardness of 6.5, easily cutting glass. In color it is generally milk white or pink. It fractures in plane surfaces. Orthoclase gives a smooth fracture, and Plagioclase has a striated fracture. Rocks containing Quartz generally carry the Orthoclase variety of feldspar. Due to its ease of cleavage water enters readily, and a rock high in feldspar should always be examined as to the amount the feldspar has broken down under the action of the water. Kaolin is the result of this decomposition.

Nepheline or Nephelite, $NaAlSiO_4$, a mineral prominent in igneous stones in many localities, is not abundant in Georgia igneous rocks. It is very similar in physical properties to the Feldspars, and can only be determined from them megascopically with difficulty, or by chemical tests.

Mica, a potash, magnesia and iron compound with silicic acid occurs in three distinct forms generally differentiated by their colors. Muscovite or white mica, $H_2\ K\ Al_3\ (SiO_4)_3$; Phlogopite or amber mica, $H_2\ K\ Mn_3\ Al\ (SiO_4)_3$; Biotite or black mica, $(HK)_2(MgFe)_2Al_2(SiO_4)_3$. They are all soft and can be easily cut with a knife. They crystals are hexagonal and have a marked tendency to cleave crosswise giving rise to the familar sheets used extensively for insulating purposes in the electrical industry. It does not weather readily although Biotite is more subject to decomposition than is Muscovite.

Amphibole is a mineral group of which an outstanding example is the mineral Hornblende, $Ca(MgFe)_3(SiO_3)_4$ with $Na_2\ Al_2(SiO_4)_3$ and $Mg_2Al_4(SiO_6)_3$. They have a hardness of 5 which is the same as ordinary glass and are generally dark green, brown or black in color. The crystals exhibit cleavage in two directions lengthwise at 125^o to each other. It can be distinguished from the micas by its superior hardness.

Pyroxene is a group name of which Augite, $Ca\ Mg(SiO_3)_2$ with $MgAl_2SiO_6$ and $Na\ Al\ Si_2O_6$, is a good example. In physical properties it is almost identical with the amphibole, Hornblende. The amin difference is that the two cleavage planes running lengthwise in the crystal meet at an angle of 90^o in Augite and 125^o in Hornblende.

Olivine, $(MgFe)_2SiO_4$, is a complicated silicate of lime, magnesia, iron and alumina, similar to the amphiboles and pyroxenes. It differs from the others though in having a hardness of 6.5 and a different crystalline structure. It can be identified by its olive green color, glassy luster and association with the heaviest and darkest igneous rocks.

The above constitute the essential minerals found in igneous rocks.

The most common accessory minerals found in Georgia igneous rocks are:

Garnet, a stone of viterous luster and red color having a hardness of 7, and which adds to the beauty of the stone in which it is found.

Magnetite, an oxide of iron occurring as small black grains in the stone matrix gradually alters to a yellowish brown, discoloring the stone adjacent to it.

Hematite, an oxide of iron occurring in several forms, turns red and then brown upon weathering. It does not spread discoloration as does Magnetite.

Pyrite, known as fool's gold, a sulfide of iron has a golden color. It breaks down easily and badly stains the stone in which it is found.

Tourmaline, a stone of viterous luster occurring in triangular crystals having a hardness of 7, is found in several colors, varying from pink to black.

In granites it is usually associated with Boron spots and has no objection other than breaking the continuity of the even texture of the stone.

The above is based upon observations upon granites from the Stone Mountain area, the Lithonia area, and three granites from the Elberton area which constitute the main igneous quarry sections of the state.

However, in Bulletin 9-A of the Georgia Survey on the Granites and Gneisses of Georgia, Watson[1] quotes from Merill[2] the following:

CONSTITUENTS OF GRANITES

Essential Minerals

Quartz	
Orthoclase)	
Microcline)	
Albite)	Feldspar Group
Obligoclase)	
Labraderite)	

Accessory minerals

Characterizing Accessories		Microscopic Accessories
Muscovite)		Sphene
Biotite)	Mica Group	Zircon
Phlogopite)		Garnet
Lepidolite)		Danalite
Hornblende		Rutile
Pyroxene		Apatite

1. Granite and Gneisses of Georgia, Watson; p. 21
2. Tenth Census Report on Building Stone of the United States; p. 16

Epidote	Pyrite
Tourmaline	Pyrrhotite
Acmite	Magnetite
	Hematite
	Llmentite

Secondary Minerals due to Weathering and Altering

Chlorite	Calcite
Epidote	Muscovite
Uralte	Limonite
Kaolin	Hematite
	Magnetite

The above tabulation contains every possible mineral that can be found throughout the country in an igneous rock, and they are grouped according to the country as a whole. An effort was made in the preceding discussion to satisfy local conditions; i.e., State of Georgia only.

GRANITE

Quoting Watson[1], "the term Granite is used to designate any holo-crystalline, massive, granular rock, of igneous origin, composed of the essential minerals, quartz and potash feldspar, either orthoclase or microcline or both. Usually, one or more minerals of the mica, amphibole or pyroxene groups are present, to the extent of imparting some distinctive character to the rock." Parks[2] in his report

1. The Granites and Gneisses of Georgia, Watson; p. 19
2. Building and ornamental stones of Canada, Parks; p. 11

on Canadian Stones closely agrees with this when he states, "In a typical granite the constituent minerals are quartz, orthoclase and mica; the first two are always present while the mica which may be on any variety is frequently replaced by augite or hornblende, more commonly the latter."

Watson[1] defines granites as follows: "Structurally, the granites are holo-crystalline, granular rocks and as a rule, without perfect crystal outline (allotriemorphic) displayed in the essential minerals. The feldspars, however, approach more or less perfect (idiomorphic) forms at times, when the structure is referred to as hypidiomorphic-granular. This irregular crystalline outline of the constituent minerals (anhedra) has been determined by interesting crystallization resulting in each mineral assuming the form imposed upon it by its growing neighbors. As original products of crystallization from a molten magma and interference on consolidation, the individual minerals are rendered not only irregular in crystal outline but the general grains interlock in an intricate manner, imparting thereby a high relative strength to the rock. The constituent grains vary in size from several inches

1. Granites and Gneisses of Georgia, Watson; p. 22

down to being scarcely discernible by the naked eye." Which means in regard to its structure that granite is composed entirely of minerals; there is no glass or uncrystallized material between constituent grains, and on account of close contact the individual minerals have not been able to assume their normal shapes or expand to any great size. The result is an even grained texture which is characteristic of granites and sometimes referred to as a "pepper and salt" texture.

Dale[1] gives the following on grain structure: "Three grades of texture may be distinguished: Coarse, in which the feldspars generally measure over 1 cm.; medium, in which they measure under 1 cm. and over 0.5 cm.; fine, in which they measure under 0.5 cm. In some coarse granites the feldspars measure one or several inches, and in some fine-grained ones, all the particles range from 0.25 cm. to 1 mm. in diameter, and some average as low as 0.25 mm. Extremely fine ones average 0.175 mm. or about seven one thousandths of an inch. At times cases are met with where on mineral occurs in larger crystals than the others. These are known as phenocrysts, and a granite containing these phenocrysts is known as a porphyritic granite."

1. U. G. S. Bulletin 313, Granites of Maine, Dale; p. 20

SYENITE

This igneous rock which is often confused with Granite is composed of even sized mineral crystals of which Orthoclase is the most important. Associated with the Orthoclase is mica, hornblende, or augite, or any two of them, rarely three. Quartz is not present and this is the distinguishing characteristic between this rock and Granite. As with granites the varieties are identified according to the accessory minerals present. Hornblende Syenite is Syenite proper. Generally Syenites are darker colored than the granites, although both owe their coloring to the feldspar present.

PORPHYRY

Although generally speaking, a porphyry is a rock in which large phenocrysts occur, in the limited sense it refers to a rock of the same mineral and chemical composition as Syenite, but instead of having an even-grained texture, the Orthoclase occurs as phenocrysts in a finer-grained ground mass of the associated minerals. This difference in texture is brought about by the consolidation in the latter case of the molten material in fissures while attempting to escape to the surface resulting in imperfect crystallization of all the minerals on account of the greater speed in cooling.

GREENSTONE

Although this term has no real significance other than it includes a series of igneous rocks of a dark green to black color, it is commonly used. While these rocks are very tough and heavy, their mineral constituents are more likely to decompose than those found in either the granites or syenites. Rocks of this group include, Diabase, Gabbro, Diorite, Basalt, Andesite, Pyroxenite, and Peridotite. It is very seldom that they are encountered as building stone.

PORPHYRITE

Although this might be considered as another of the Greenstones, it differs inasmuch as the feldspar is plagioclase instead of orthoclase. Otherwise, it is very similar to Porphyry. However, the difference in feldspars makes it unfit for a building stone as it weathers very rapidly.

ANORTHOSITES

Rocks composed almost entirely of feldspar are generally grouped under this head.

SEDIMENTARY ROCKS AND MINERALS

Although the minerals associated with the sedimentary rocks are abundant in Georgia, the rocks themselves are decidedly limited from a commercial standpoint. There are no active quarries in which sandstone is being quarried, and at present the existing limestone quarries are closed. Current economic conditions have closed the Georgia Travertine quarries, and only the Kaolin and Marl deposits are being worked.

As originally outlined, sedimentary rocks are those which have accumulated in bodies of water. The materials were either transported by mechanical action or in solution by streams feeding the large bodies of water in which they were deposited. Since this is the case, we should expect to find all those minerals that make up igneous rocks in sedimentary rocks, for the material acquired was from these disintegrated igneous rocks. However, it must be borne in mind that the hammering, abrasion and wear of stream transport would change the physical appearance of all except the most resistanct of these minerals. Again, many minerals when exposed to the leaching action of meteoric waters, and the action of gases in the atmosphere undergo chemical changes causing the formation of new minerals. In consideration of these factors it is, therefore, not strange that the minerals found with sedimentary rocks seem to differ decidedly from those encountered in igneous rocks. Then admitting those minerals mentioned under Igneous Rocks and adding the minerals of secondary origin, this should give the minerals that might be expected in sedimentary rocks.

CALCITE

When any igneous mineral containing lime disintegrates as a result of weathering, the lime combines with the carbonic acid gas of the atmosphere forming carbonate of lime. This is an elementary chemical equation involving a double reaction:

$CO_2 + H_2O \rightarrow H_2CO_3$

$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O$

This resultant $CaCO_3$, carbonate of lime is very soluble in water and is transported by streams to be later deposited. The mineral Calcite is crystallized carbonate of lime. It is softer than glass, having a hardness according to Moh's Scale of Hardness of 3. It occurs in any variety of colors, cleaves with facility into rhombohedral blocks, and effervesces violently with any strong acid. The large crystals resemble quartz in appearance but can easily be distinguished by their inferior hardness. However, this mineral occurs in various forms. The great bulk occurring in limestone in which it is found as a fine crystalline mass.

DOLOMITE

Dolomite, Ca Mg $(CO_3)_2$, is a carbonate of lime and magnesia and very closely resembles calcite. The physical properties of the two are identical and they can only be distinguished by the fact that dolomite will not react with cold acids as calcite, but will react with hot acids. It occurs in great beds resembling the limestone beds.

GYPSUM

Gypsum or Selenite, a hydrous calcium sulphate, $CaSO_4 2H_2O$, is very soft and can be scratched with the thumb nail. When in the pure crystallized form, it is, as a rule, of dazzling white color and is known as Alabaster.

KAOLIN

Kaolin is an aluminum silicate, $H_2Al_2Si_2O_9$.

It is formed on the decomposition of the feldspars. The soluble parts are removed by circulating waters, leaving a fine, white, plastic material which is the Kaolin. Where this Kaolin has been washed by streams and redeposited; as, just below the Fall Line in Georgia, it is known as Sedimentary Kaolin. The distinction being that here it occurs in huge beds that have been deposited by stream action rather than en situ as in the northern part of the state. Kaolinite is generally considered the base of all clays.

In the following list of sedimentary rocks only the most important ones will be mentioned.

SANDSTONE

There are many types of sandstones, and as a result there are many desirable for building purposes and many that are undesirable. The particles that are borne along by the streams and deposited by the decrease in velocity upon entering larger bodies of water are sorted or gradiated immediately. The coarse particles will be deposited first, and the fine silt will be carried for a considerable distance before it is dropped. Due to changing conditions the ocean bed is built up of alternating strata ranging from coarse to fine deposits and back again, and as a result of this, very few sandstone beds are of any great thickness. Either they grade into shale or a conglomerate. However, after the sand itself has been consolidated into sandstone there are many factors affecting its worth as a building material, chief of which are:

a. The mineral character of the individual grains

b. The size and shape of the grains

c. The arrangement of the grains within the rocks

d. The nature of the cementing material between grains.

Considering the first, the mineral character of the grains, particles of Quartz are the most predominant although Feldspar occurs frequently to a large extent. In some regions this is so pronounced that the sandstones are divided into Feldspathic and Non-feldspathic groups. A feldspathic stone, on account of the high feldspar content is not desirable as a building stone for it weathers easily and soon crumbles. However, there are exceptions to this where the cementing material is such as to protect the feldspar grains from the action of the weather. Likewise, there are exceptions to the desirability of the quartz sandstones, particularly where they are so hard that they cannot be worked without great expense. When mica occurs in a sandstone it is generally found bedded in strata which will have a tendency to cause a crack at this point. This is not due to the weathering of the mica so much as it is to the fact that on being deposited the flat flakes lie parallel to the bedding and the cementing material and cannot form a good bond across these flakes with the result there is an inherent weak place liable to split when put under any strain.

Considering the size and shape of the grains, it is obvious that grains that have been tramsported long distances will be smaller and more rounded than those which have only been carried short distances. A stone having rounded grains is more easily worked than one having angular grains, but the latter has more strength.

The arrangement of the grains within the rock is important for where there is a mixture of coarse and fine grains there will be a tendency for the different size particles to be arranged in layers which will result in a pronounced tendency to split along these layers.

The nature of the cementing material is just as important as the nature of the grains themselves. The material may consist of silica, calcium carbonate, iron oxide, or clay. Sandstones are generally divided according to this cementing matrix into groups; i.e., the siliceous, calcareous, ferruginous, and argillaceous.

Siliceous sandstones have the highest strength, but on account of their hardness and difficulty of working are very seldom used.

Calcareous sandstones are soft, easily worked, but weather rapidly especially in districts where there is much smoke. This is due to the reaction of the calcium carbonate matrix with dissolved acids in the atmosphere.

Ferruginous sandstones are somewhat harder than the calcareous stones, and once were used a great deal for town dwellings. They are of a red or brown color, and sometimes are known to the trade as Redstone or Brownstone.

Argillaceous sandstones weather easily. This is due to their high absorption of water which makes them spall quickly under frost action.

Other sandstones which consist almost entirely of mineral grains with very little bond material have variable properties, and no definite conclusions can be set down on the groups as a whole.

Sandstones occur in almost any color, some even being bright blues and violets.

CONGLOMERATE

Conglomerates are formed in the same manner as sandstones, the difference being in the size of the particles. Generally these particles are rounded pebbles indicating their water transportation. In fact this is the sole distinguishing point between a Conglomèrate and a Breccia. The particles are about the same size as those found in a Conglomerate, but in a Breccia they are angular indicating their deposition by glacier action rather than stream transportation.

CLAY AND SHALE

As mentioned under Kaolins, this mineral constitutes the base of all clays, and with certain other minerals makes up the entire body when mixed with sand, lime and other impurities. Clay beds which have hardened during the passage of time become shales. With the exception of the use of adobe clay or gumbo in arid climates for building purposes these materials cannot be considered as building materials unless as the raw material for brick.

LIMESTONE

Limestone is a rock composed almost entirely of calcium carbonate. This mineral is brought in solution by streams to sea waters where, in the majority of cases, it has been extracted by minute organisms and then redeposited as calcareous body parts, shells, etc. which ultimately became consolidated into rock. A limestone consisting of pure calcium carbonate is very rare as it would require that the water in which the limestone was deposited should be free for a considerable time of turbidity. As a result we find that limestones are classed, as were sandstones, according to the ranking impurity present. This gives rise to the arenaceous limestone containing sand; the argillaceous limestone which contains clay; the ferruginous limestone containing some iron oxide; and bituminous limestone. Another division which really sets up another stone is where some of the calcium has been replaced by magnesia giving rise to a dolomite limestone. As already mentioned under sedimentary minerals the dolomite is similar in every respect to the calcite limestone except that it will not react to cold acids. Other divisions are Oolithic limestone which consists of an aggregate of small spherical concretions; Lithographic limestone which is a dolomite with some clay used in lithographic work and which is found in Bavaria; and Hydraulic Limestone, a stone containing some clay which upon being burned gives a cement that will set under water.

Arenaceous limestone generally occur in thin beds and were at one time much used for flag stones.

Ferruginous limestone may contain the iron as carbonates, oxides or sulphides. Generally this mineral darkens the tone of the stone.

Bituminous limestone contains some bitumen of orgainic origin contemporary with the consolidation of the stone. It gives a very dark color that is not uniformily distributed.

Limestones occur mostly in greys, but can be obtained in almost any color desired.

CHALK

Chalk is a very fine-grained, friable limestone composed of shells of minute sea animals known as foraminifera.

TRAVERTINE

Travertine is a deposit of calcium formed by springs. It is much used for interior trim. The Roman or Italian Travertine is perhaps the best known.

MARL

Marl is a loose earth material and as a rule is composed of a carbonate mixed with clay in various proportions. In Georgia there are many marls composed entirely of fossil sea shells cemented together with a siliceous or carbonate matrix. It makes a very good interior trim and is known as Georgia Travertine.

METAMORPHIC MINERALS AND ROCKS

Metamorphic rocks are rocks which have undergone some physical or chemical changes subsequent to their original formation. This change is generally brought about by heat and pressure resulting from diastropic disturbances in the earth's crust. As a result new minerals are formed, physical readjustment of mineral particles takes place, and a new rock is formed regardless of whether it was once of igneous or sedimentary origin. Such a rock is known as a metamorphic one.

Although there are many minerals which result from metamorphism, practically all of them have been mentioned in the list of minerals under igneous rocks, and need not be relisted here.

GNEISS

Gneiss generally refers to a metamorphised granite. In the strict sense of the word it is a metamorphic rock composed essentially of quartz, feldspar and mica. The quartz and feldspar occur together in layers which are separated from each other by thin bands of mica. This banded appearance is characteristic of metamorphic rocks as the pressure under which the original rocks are subjected cuases the like minerals to segregate together in thin layers. Usually gneisses are light in color, but they vary according to the accessory minerals. As a result there are biotite-gneiss, hornblende-gneiss, granite-gneiss, diorite-gneiss, etc. It is possible for gneisses to have been formed from sedimentary rocks where the metamorphic action has been very intense.

QUARTIZITE

Quartizite is the result of intense metamorphism of siliceous sandstone. The grains have been pressed very close together, and the mass has become exceedingly hard and breaks with a splintery or conchoidal fracture. Although it takes a very high polish, it is not much used on account of the high cost of working it.

MICA-SCHIST

Mica-schist is composed of essentially mica and quartz, and though very abundant, has no use as building stones. Due to the cleavage planes of the mica all being arranged in the same direction, the rock gives a very schistose appearance and as a rule contains many of the accessory minerals; as, garnet, staurolie, epidote, etc.

SLATES

Slates are very fine-grained rocks which exhibit a very marked cleavage in one direction which permits them to be split into thin sheets. They are formed by the intense metamorphism of shales. Strong lateral pressure is what gives them their slaty cleavage and as a result this cleavage has no relation to the original bedding planes. These rocks occur in any number of colors, the most common being a drab or grey.

MARBLE

Marble in the correct sense is a fine, even aggregate of calcite crystals produced by the metamorphism of a limestone. Many stones capable of taking a high finish are commercially referred to as marbles, but a true marble is the product of intense heat and pressure on limestone. Pure marble is white in color, but very few deposits are found where there have not been some impurities present which have resulted in color changes. As a result there are found marbles of almost any color, with varied clouding and banded effects. The size of the crystal of calcite vary just as the color giving variety for different building and ornamental work needs.

SCHISTS

Just as metamorphism converted a granite into a laminated gneiss, so other igneous rocks by the same action have been converted into what is known as the crystalline schists. These are often used for flag stones.

SERPENTINE

Those minerals that make up the heaviest and darkest of the igneous rocks as the Greenstones under metamorphic action, are converted into a softer green mineral known as serpentine. Serpentine has a greasy, wax-like luster and is about 6 in hardness. During transformation this mineral is often shot through with veins of calcite which give it a very pleasing appearance. Slabs of this are known on the market as Verde Antique or Ophiolite and are much used for interior trim and outside finish as well.

TALC

Talc is a very soft mineral that occurs massive and as crystals. The massive form is known commercially as soapstone and has varied uses. It is found in the same sections as serpentine, and is very much like it in appearance.

Although the main rocks have been covered there still remains a group that has not been included and which finds a use particularly in the ornamental stones. These are the cave and vein deposits which are mostly the result of precipitation from underground waters.

VEIN AND WATER DEPOSITED ROCKS

THE ONYX MARBLES

As already mentioned in the weathering of limestones, rain water becomes charged with the carbon dioxide in the air forming dilute carbonic acid which, on being absorbed in limestone regions attacks the limestone carrying off calcium carbonate in solution. This water on entering fissures or caves of any size, upon evaporation, precipitates the calcium carbonate where it forms deposits. In caves the deposits hanging pendant from the roof are known as stalctites, and accumulating deposits rising from the floor are known as stalagmites. This action continues until the entire cave is filled, and the resulting stone is known as cave onyx. Likewise, hot springs forcing their way up from below may give rise to the same formations. In this case the deposits are known as Travertine which has already been mentioned under the head of Sedimentary Rock.

VARIETIES OF SILICA

Many cavities, veins, etc., are often filled with quartz. Generally these deposits are of the white quartz but often they are of rose quartz, amethyst quartz, smoky quartz, etc., and when a deposit is found with these varieties intermingled it is mined and used for interior trim.

Chalcedony is a mixture of crystallized and amporphous quartz and occurs in various colors. One variety is blood stone.

Jasper is a cryptocrystalline variety of quartz, generally colored yellow to red. Where it occurs in beds of sufficient size, it finds use as a building and ornamental stone.

Agate, onyx, and sardonyx are similar to chalcedony in structure and are generally laminated showing their precipitation from silica-bearing underground waters. They only have use as ornamental stones.

MALACHITE AND AZURITE

These two minerals are compounds of copper, carbonic acid and water. Malachite is green in color, and Azurite is blue. According to Moh's Scale of Hardness they are about 4.5. They are formed by the decomposition of copper ores which have been redeposited by meteoric waters in the form of carbonates. They have a wavy, banded appearance and find use for interior trim and ornamental work.

It might be well to mention that most of the material filling veins is crystalline and contains many minerals. Most of the gold that has been found in Georgia has been in water-deposited quartz veins. According to Parks[1] in the Lake Superior region gangue material of pink and white calcite containing filaments of native silver and threads of silver ores have been used for interior trim.

Other stones used for ornamental work are: Jade, a dark green stone which is generally regarded as a gem stone; Lapislazuli, a hard blue stone of which there are limited vein deposits in crystalline form in Graves Mountain, Lincoln County, Georgia; Turquoise, a blue gem stone; Meerschaum, a composition very similar to talc; amber, a fossil vegetable rosin; Fossil wood, such as occurs in the Petrified Forest of Arizona where it is a silica replacement of varied colors; Volcanic Tuff which has been cemented together and is sometimes used as a building stone and Field stones

1. Building and Ornamental Stones of Canada, Parks; p. 34

which are very common in areas that have been subjected to glaciers and ice sheets. Also might be mentioned the shell deposits that have been cemented together artificially, as well as naturally, to form a building material that is peculiar to the coast of Georgia known as Tabby. The shells used are generally oyster shells obtained from the large shell mounds found along the coast.

STRUCTURAL AND GEOLOGIC FEATURES AFFECTING THE USES OF STONES

Those deposits previously mentioned as being formed in veins and cavities will be omitted in this discussion and only those three main divisions of rocks, the igneous, sedimentary, and metamorphic will be considered.

As has been pointed out, the igneous rocks are those which have consolidated from molten magma, the rate of cooling determining the texture of the rock. Granites are formed on the whole from lenticular masses consolidated deep within the earth's crust. The porphyries occur in sheet-like masses filling fissures in older rocks. Lavas are those masses which have consolidated on the surface of the ground.

Considering the granites as being formed in deep seated deposits it is observed that all extensive deposits of granite have a dome-shaped appearance after the removal of the overburden, and there is a tendency for the rock to be formed in radial layers from the center to the outside. Stone Mountain, Georgia, exhibits this shape and tendency and is a good example of what is known as a batholithic boss. The term batholithic referring to its deep-seated origin and boss referring to its dome shape. Quoting Parks[1], "Dale in his report on the Granites of Maine sums up his observations on 100 quarries in Maine as follows:

1. 'There is a general parallelism between the sheets and the rock surface, resulting in a wave-like structure and surface over large areas.

2. The sheets increase in thickness more or less gradually downward. In the coarse-grained granites of Crotch and Hurricane Islands the increase is abrupt.

3. The sheets are generally lenses, though in some places their form is obscure. Their thick and thin parts alternate vertically with one another. The joints that separate these superposed lenses, therefore, undulate in such a way that only every other set is parallel.

4. On Crotch Island the sheet structure extends to a depth of at least 140 feet from the surface.

5. There are indications here and there that the granite is under compressive strain, which tends to form vertical fissures or to expand the sheets so as to fill up small artificial fissures.'

"Dale's summary of the possible causes of the sheet structure is as follows:

1. 'To expansion caused by solar heat after the exposure of the granite to erosion.

1. Building and Ornamental Stones of Canada, Parks; p. 36

2. To contraction in cooling of the granite while it was still under its load of sedimentary beds, the sheets being, therefore, approximately parallel to the original contact surface of the intrusive.

3. To expansive stresses or tensile strain brought about by the diminution of the compressive stress in consequence of the removal of the overlying material.

4. To concentric weathering due to original texture or mineral composition.

5. To compressive strain akin to that which has operated in the folding of the sedimentary beds.

6. To the cause named under 1 at the surface, but to the cause named under 5 lower down.'"

Jointing, which is that parting of the stone perpendicular to the bedding plane, is found in granite, and is not desirable since where the joints are too close together it makes it impossible to get out dimension stone. Likewise, where the planes are on too great an angle it makes quarrying difficult. Where the joints are extremely close together, it is referred to as a heading. A heading may continue quite a way down into the rock, and then it may pass out in a relatively short distance. Frequently faults are encountered with their resultant slickensides. A fault occurs where there has been a displacement either up or down of one section of rock relative to the other. Along the fault line, the line of movement, the particles of rock are crushed fine giving a slick polished surface. This is known as a slickenside and indicates the fault line along which displacement took place, Along joints are often found small cracks radiating from the main joint. These are called subjoints. Most volcanic rocks have a characteristic tendency for the joints to cleave the mass into polygonal columns.

Although the joints and sheet structure more or less divide the granite up into blocks, there are cleavage tendencies that are taken advantage of in quarrying and working this stone. That direction in which the granite splits with the greatest ease is called the "rift." At right angles to the direction of rift runs the "grain" in which direction the stone splits almost as easily. That direction perpendicular to both the rift and the grain is known as the "head", and in this direction it is almost impossible to split the stone. As found in the quarry, the rift is approximately horizontal or vertical. When found horizontal it is generally parallel to the sheet structure planes. This qualification is made as the rift often occurs at right angles or at some other angle to the sheet structure. The fact that close examination shows that the rift is parallel to the flattened mineral particles, and the grain which is at right angles to it occurs in the direction of elongation tends to show that these qualities are dependent on subsequent pressures applied to the rock mass after consolidation. Where this subsequent pressure has been exerted to such an extent that the rock has become metamorphised, the mineral constituents will be found in laminations which are characteristic of gneisses.

As already mentioned, those magnas which consolidated in fissures would be porphries due to the finer crystallization of others. Dykes are fissure deposits more resistant than the country rock and where exposed in the mould of the fissure after extensive erosion form a wall or dyke.

The surface flows, or volcanic rocks, as previously mentioned, have a typical polygonal jointing and are generally glassy, ropy, or pneumatic in appearance.

All of the structural features mentioned for granite can be applied to the other igneous rocks as they are of similar origin and differ only in mineral constiuents.

The sedimentary rocks, also known as the stratified rocks or series were originally laid down in a horizontal position. The strata vary in thickness and in composition. Where the strata are thin and the stone varies from conglomerate to limestone to shale to sandstone, etc. there can be no building stone, for quarrying operations for any one particular stone would be too expensive, and then again the size of the stone would not justify exploitation. As a rule limestones are found in the tickest beds as they are generally formed in deep water not subject to change as shore deposits, and also they are formed from material which has been precipitated and taken out of solution rather than from matter held in suspension by littoral currents. As fine material in suspension more nearly approach a colloidal condition than coarse material, the shale deposits are more extensive than the sandstone and conglomerate deposits. After the layers of material were deposited, they later became separated by planes of parting or bedding planes. For dimension building stone, it is desirable that the bedding planes should not be too close together as the stone will split along these planes with little provocation. Where a sedimentary stone parts in other than a bedding plane, it is generally due to the shearing action of the load on top of it and in this case the parting is known as a cleavage plane.

When a sedimentary stone undergoes shrinkage due to contraction and expansion vertical parting generally in two directions, takes place. These are joints, and the same comments used under igneous rocks apply here. Although jointing roughly divides the stones into large blocks making quarrying easier, it is not desirable as it causes excessive waste.

It is very seldom that sedimentary rocks are found in horizontal position as they were first deposited. The beds are generally contorted, so that erosion has laid bare the whole series of strata for considerable depth. The angle which the bed makes with the horizontal is known as the angle of dip, and the compass direction in which an inclined bed cuts the horizontal is known as the strike. The strike is always at right angles to the direction of dip. For example, suppose a bed inclines from the horizontal 20° in a Northwest direction, then the upturned edge which breaks ground must run at right angles to this or in a Southwest direction. This bed would be recorded as Strike--Southwest; Dip--20° Northwest. This is of value as one traveling perpendicular to the strike direction can inspect all of the strata exposed of that particular fold.

Although not mentioned under granite, the following might be applied to it and all stone. Surface deposits generally have little value for as a rule they contain much sap stone which means that they have been discolored by percolating waters, and in addition have undergone some deterioration as well as spalling and cracking. Therefore, valuable commercial stone is obtained only from depostis of sufficient depth to have been protected from weathering agents.

The metamorphic rocks are found in only those localitites which have been subject to great strain and alteration.

As previously mentioned, gneisses and crystalline schists, the metamorphic equivalents of igneous rocks, have a typical banded structure due to mineral segregation and naturally split easily along these laminations. Due to much contortion these rocks are often jointed as the result of tensile strains.

Marble, the metamorphic component of limestone, is generally found in narrow deposits associated with dykes, gneisses, slates and eruptive deposits. Although all original planes of parting have been obliterated by subsequent action, these original characteristics affect the quality of the stone and its ease of quarrying. Marble deposits generally conform to the contortion of the original strata and are often fissured.

Slate deposits represent that part of an original shale deposit that has been under the greatest strain in the folding of the earth's crust. They generally run parallel to the chief axis of mountain chains and as a result are generally narrow but of some length. The slate cleavage is along the axis of the deposit, and these planes of cleavage are generally vertical or on high angles nearly perpendicular to the original bedding planes as a result of the intense pressure that was applied at right angles to the deposit. Slates are frequently jointed and the joint planes run across the strike at right angles to the cleavage planes.

REQUISITES OF BUILDING STONES

As structural stone is employed for so many purposes, no one characteristic can be regarded as paramount. Bridge piers would call for high crushing stress rather than uniformity of color which might be most desirable for interior trim. However, generally speaking, the characteristics that must be considered in choosing a building stone are:

1. Strength
2. Color
3. Durability
4. Cost of Working

Although some of these characteristics might be considered as corollary to each other, they can be considered as separately.

STRENGTH

In all building work it is good engineering practice to use material with a factor of safety sufficient to take care of any overloads that might possibly be applied to the structure above designed conditions. As in other building materials it is important to know the compressive strength, transverse strength, and modulus of elasticity of the stone to used.

Formerly there was a great deal of stress laid upon the crushing strength of a stone. However, there are very few stones even of the poorest grades that would have a crushing strength so low as to make them unsafe. Watson[1] states, "It is now generally agreed that a stone possessing a compressive stress of 600 pounds per square inch is sufficiently strong for all ordinary building purposes. Merrill[2] gives the following summary of tests on American stones:

Stone	Ultimate Stress in Lbs. per Sq. In. Maximum	Minimum	Average
Granite, 100 tests . . .	28,000	6,117	17,000
Limestones, 80 tests . .	25,000	3,550	14,000
Sandstones, 132 tests . .	20,000	1,149	8,500

The above results indicating that any of the above stone would be safe for building purposes as far as compressive loads are concerned. However, there are exceptions met with where there are excessive loads placed at one point as a result of moving loads as met with in railway tressel pier construction. As a general thing it will be found that stones having a high compressive stress are more compact, and as a result, more durable than those stones having a lower compressive strength. However, there are exceptions, and durability should always be separately determined rather than accepting compressive test results as a guage of this quality.

1. Report on Granites and Gneisses of Georgia, Watson; p. 52
2. Stones for Buildings and Decorations, Merrill; p.65

The transverse strength of a stone is its ability to act as a simple beam with two point suspension loaded at some point with a concentrated load. There is no direct relationship between compressive strength and transverse strength as the latter will vary as to whether the beam is loaded on edge or flat. Its most important use is in figuring the size of a lintel in a door to carry a certain load.

The modulus of elasticity is an arbitrary quality arrived at by mathematical equation expressing a relationship between load per square inch and unit deformation for that load.

COLOR

Although color is not as important as strength or durability, it is generally given first attention in picking a building stone. To the average layman stone is stone, the differences are mostly in color. However, as color is determined by mineral constituents it is well to consider the use to which a stone is going to be put before deciding upon the color. A stone easily discolored and stained by smoke wouldn't do for a railway depot, and neither should granite having a dull cast be used for building purposes as this indicates that extensive weathering of the feldspar has already taken place.

Fine-grained stones, of even texture, and solid color generally are the most desirable for building purposes. For interior trim though, variegated colors are often desirable in a stone to break the monotony of the flat color generally met with on the walls and ceiling of buildings.

DURABILITY

No stone that cannot stand up under atmospheric conditions and last during the designed life of the structure should be used, regardless of its color or ease of working. Durability is a resultant of several properties such as, chemical composition, porosity, hardness, and other inherent characteristics. Although the true test of durability is actual service, it is sometimes difficult to find a criterior for judging the durability of a stone. According to Merill's[1] observations on buildings in New York the average life of a stone in that climate; i.e., period before repairs are necessary, is approximately as follows:

Stone	Life in years
Coarse brown stone	5 to 15
Fine laminated brown stone	20 to 50
Compact brown stone	100 to 200
Coarse fossiliferous limestone	20 to 40
Fine oolitic limestone	30 to 40
Marble, fine dolomitic	60 to 80
Marble, fine	50 to 100
Granite	75 to 200
Gneiss	50 to infinity

1. Stone for Building and Decoration, Merill; p. 453

Durability may be divided up into two general heads, the durability of color, and the general durability of the stone. Very few stones hold their original color after weathering for a while. Some take on a mellow look which improves their appearance while others, due to minerals, discolor badly, or take on a dull flat appearance. Perhaps the greatest discoloring agent encountered in a stone is unoxidized ferrous salts. Chief of these are marcasite and pyrite which upon oxidation result in unsightly yellow and brown splotches. Their presence can be determined by chemical analysis or by stimulating extreme weathering conditions artificially by the use of acid vapors. Limestones upon weathering generally take on a more mellow appearance, while granites due to the changing of the feldspars to kaolin will take on a flat, clayey appearance. However, this change is very gradual and would require a great many years.

GENERAL DURABILITY

The dictionary definition of durability can be summed up in one word, "endurance," and this is what is to be considered under the head of general durability. As a general rule, a stone to be used for interior trim does not have to be as durable as a stone used for outside construction. Likewise, a lintel would not have to possess the same wear resistance as a threshold. Therefore, any results concerning durability can only be of general value in regard to the suitability of a stone unless the class of service for which it is to be used is known.

There is no one test other than time for determining the durability of a stone. As previously mentioned under the head of "Strength", the compressive stress cannot be taken as a gauge of durability although often used as such, and neither can the practice be condoned for measuring durability by observing the changes produced in rocks by the passage of geologic time. Parks[1] quotes Hirschwald[2] on the commission appointed by the Prussian Government in 1910 for investigating this: "Such observations cannot be used, for

1. The alterations produced in stone by the agent acting in the crust of the earth are not comparable with those caused by the action of the atmosphere on stone placed in a building.

2. Changes are produced in the course of the geological ages which cannot possibly be effected in the length of time that a building stands.

3. The obtaining of a measure of the time necessary for the distinct alteration to appear in a building stone and for the time required for the alteration to proceed through different stages is not assisted at all by observations on geological weathering."

1. Building and Ornamental Stones of Canada, Parks; p. 57
2. Bautechnische Gesteinuntersuchugen, Hirschwald; p. 1

The following tests are those outlined by Parks as usually conducted for obtaining the durability of stones:

Microscopic examination
Determination of the weight of the stone
Determination of specific gravity
Determination of porosity
Determination of frost resisting properties
Determination of the softening affect of water
Determination of the effect of corrosive gases
Determination of the effect of extreme heat

As it is the purpose of this report to deal almost entirely with the durability of Georgia stones, additional tests have been added and previous test methods have been improved upon with the help of the State Department of Geology, and the Bureau of Standards of the Department of Commerce.

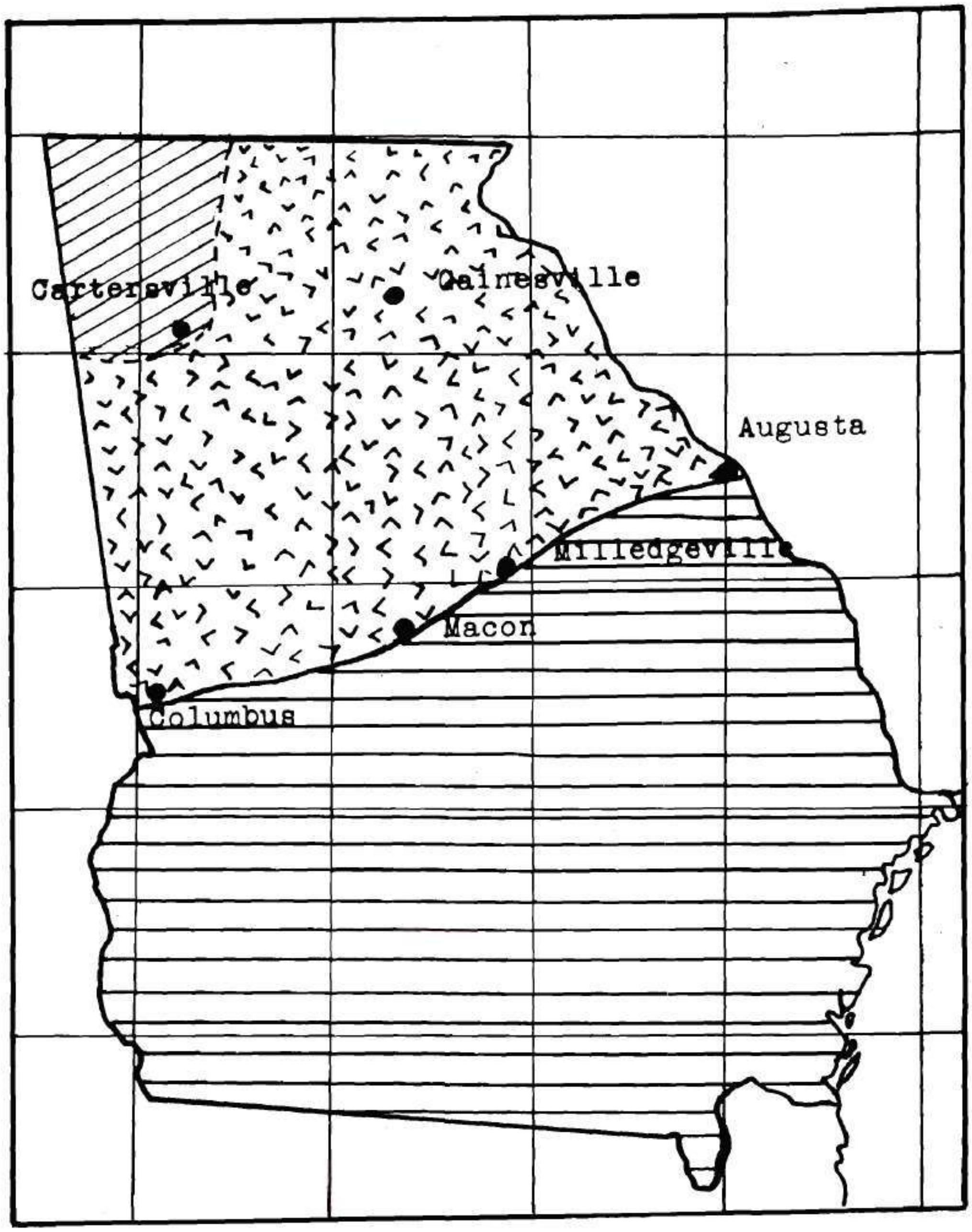
PART II

GEOLOGY AND PHYSIOGRAPHY OF THE STATE OF GEORGIA

By consulting the Geological Outline Map on Page 52 b, it will be seen that the state is divided roughly into three distinct areas. Starting from the coast and working inland are found the Coastal Plain, the Crystalline Belt and the Paleozoic Area. There are well defined boundaries of demarcation between each area and each differs from the other in regard to age, kind of rock, and topography.

Running from Augusta through to Columbus is seen a boundary separating the Coastal Plain from the Crystalline Belt known as the Fall Line. This is an irregular contact formed by the overlapping of the Coastal sediments on the upturned and highly tilted strata of ancient crystalline rocks. Likewise, in the Northwest portion of the state the boundary between the Paleozoic and Crystalline areas is well defined by what is known as the Cartersville Fault. These Geologic divisions can further be subdivided according to physiographic divisions. By consulting the Physiographic Map on Page 53b, it will be seen that the Crystalline belt includes that part of the Piedmont Plateau and that part of the Appalachian Mountains found in the state. Also, it will be noted that the

PLATE I



GEOLOGICAL OUTLINE MAP OF THE STATE OF GEORGIA

After W. S. Yeates

Coastal Plain

Crystalline Belt

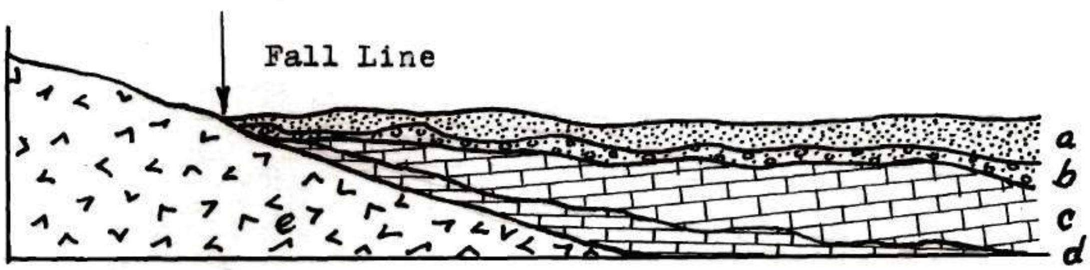
Paleozoic Group

Fault Line

Southern Fall Line

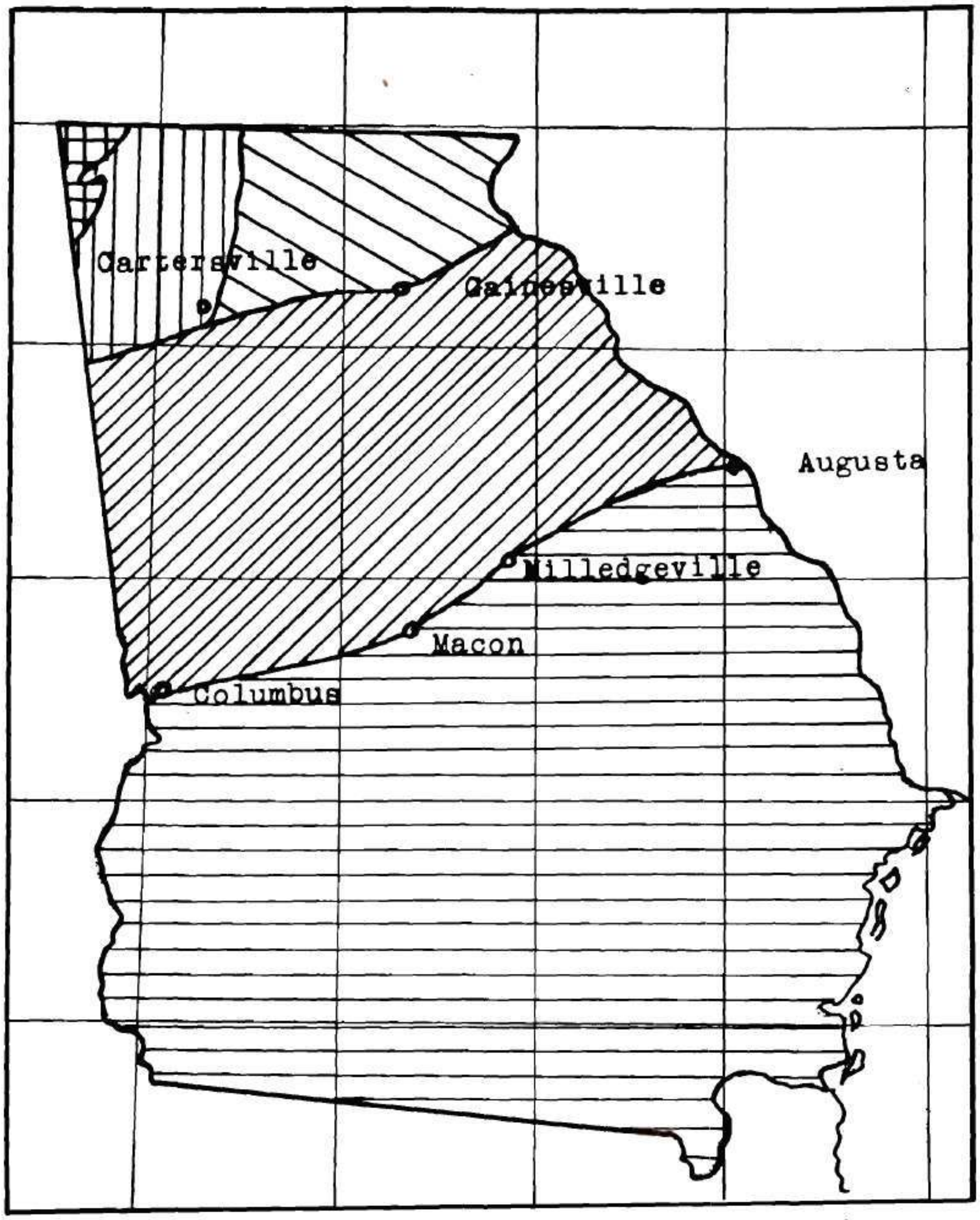
Paleozoic Group includes that part of the Appalachian Valley and the Cumberland Plateau found in the state. All of the granites are found in the Piedmont Plateau while in the Appalachian Highlands are found the highly contorted gneisses and crystallized limestones, now marble. In that section near the Cartersville Fault are found slate deposits and those limestones that have commercial possibilities are found in the Cumberland Plateau. In the Coastal Plain are found shallow limestone deposits, extensive kaolin deposits which are of sedimentary origin, sand deposits, marl, fuller's earth and peat deposits.

The accompanying illustration will show how definite the contact is between the Coastal Plain and the Crystalline Belt, and will also illustrate the different characteristics of the rocks.



e. Piedmont Plateau   a, b, c, d, Coastal Plain
a. Columbia Sands   b. Lafayette Sand, Gravel and Clay
c. Tertiary Sands, Clays, Marls and Limestones
d. Cretaceous Sands, Clays, Marls, and Limestones
e. Crystalline Rocks as Gneiss, Granite and Schists

PLATE II



PHYSIOGRAPHIC DIVISIONS OF THE STATE OF GEORGIA

After Thomas L. Watson

Cumberland Plateau

Appalachian Valley

Appalachian Mountains

Piedmont Plateau

Coastal Plain

In studying the areas adjacent to the Cartersville Fault a map of that section showing the location of the principal marble deposits will indicate clearly that the age of these deposits is contemporaneous with that of the fault. On page 74b such a map is shown, and it will be noted that the deposits run parallel to the fault line. Likewise plotting the slate deposits of the state on the same map it will be noted that these deposits also run parallel to the fault line. Therefore, as both slate and marble are products of intense diastrophic action, being metamorphic rocks, it is reasonable to assume, especially considering their position in relation to the fault line, that they are of the same geologic age as the Cartersville Fault.

Although all estimates of age in regard to rock are relative, Georgia possesses rocks which were part of the earth's original crust. These rocks known as pre-Cambrian compose the crystalline belt. Cooke, LaForge, Keith and Campbell of the United State Geological Survey did much work on the Physical Geography of Georgia and quoting them[1], "The Geology of Georgia is as diversified as its topography. The rocks of the state

1. Georgia Geology Survey, Bulletin No. 42, Physiography of State of Georgia, Cooke, Campbell, Keith and LaForge; p. 42

include classes Igneous (chiefly granites), Metamorphic (schist, gneiss, marble, etc.) and Sedimentary (sand or sandstone, clay, shale, limestone). They range in age from recent to ancient (Archean)." The table on Pages 56, 57 and 58 compiled by them in 1925 gives all the formations found in the state, their age, and lithographic form.

An examination of the map on Page 55c will give some idea as to the extent and distribution of the various rocks throughout the state.

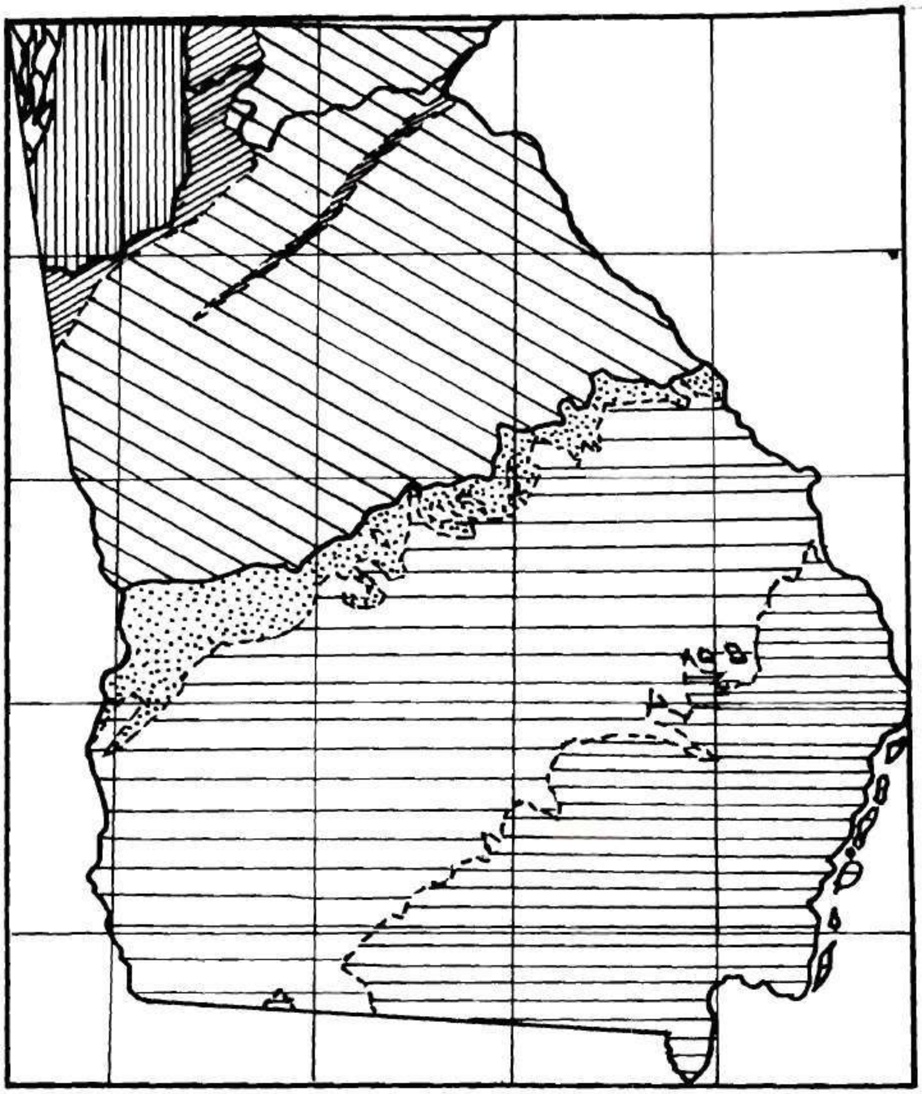
The geology of the stone-producing portion of the state is rather difficult because of the age of the formations. These formations have been so contorted and changed by diastrophic action that much has to be surmised, which with younger formations could easily be ascertained. The illustration of a specimen of Lithonia granite-gneiss on Plate IV illustrates this subsequent deformation suffered by most of the state above the Fall Line.

PLATE III

THE GEOLOGIC AND TOPOGRAPHIC DIVISIONS OF GEORGIA

After

Cooke, LaForge, Keith and Campbell



Topographic Line

Geologic Boundary

Quaternary

Tertiary

Upper Cretaceous

Pennsylvanian

Cambrian - Miss.

Metamorphic Ø

Pre-Cambrian Granite

GEOLOGIC FORMATIONS OF GEORGIA

ERA	SYSTEM	SERIES	FORMATION	PREVAILING LITHOLOGY
PALEOZOIC	Devonian	Lower	Armuchee Chert 50-100 ft.	Bedded chert, rusty and SS
	Silurian		Red Mountain Form.600-1800'	SS and sandy shale
	Ordovician	Middle West Basin	Chickamauga Limestone 1000-1500 ft	Blue LS with beds of shale
		East Basin	Rockmart Shale 1200-3000' Chickamauga LS 100-200 ft.	Black with SS and Conglomerat
		Lower	Knox Dolomite 3000-5000'	Thick beds gray dolomite
	Cambrian	Upper	Conasauga Form.1000-4000'	Olive clay shales thin LS
		Middle Appl. Valley	Rome Form. 700-3500 ft. Apison Shale 1000 ft. Cartersville Form, 600 ft.	Variegated SS and shale Sericitic schist and SS
		Highland	Nottely Quartzite 200 ft.	Massive white quartzite
		Lower Appl. Valley	Shady Limestone 800-1500 Weisner Quartzite 2000-5000'	
		Highland	Andrews Schist 50-300 ft	Calcareous schist and Iron
			Murphy Marble 50-300 ft	Massive white and blue marble
			Valley Town Form 1200-2000'	Mica schist, garnet and quartz
			Brasstown Schist 1200-1500'	Mica shcist biotite xls.
			Tusquitee Quartzite 20-600'	White glassy quartzite
			Nantahala Slate 1000-2000'	Black or gray banded slate
			Great Smoky Form.5000-6500'	Massive gritty SS, graywhacke congl.slate and mica schist
			Hiwassee Slate 1500-1800'	Dark slate and LS conglomerat
PROTEROZOIC	(?) Archean		Brevard Schist 1000 ft.	Dark Phyllite and schist with LS and quartzite
			Pinelog Conglomerate	Quartz congl. and mica schist
			Various Quartzites, Schists	Massive light colored, micaSC
			Biotite Granites	Altered to gneiss and schists
			Roan Gneiss	Hornblende G and S with gabbr
			Carolina Gneiss	Massive banded mica gneiss mica schist, garnets, cyanite and graphite.

GEOLOGIC FORMATIONS IN GEORGIA

As prepared by Wythe Cooke, M.R.Campbell, Arthur Keith and L.Laforge

ERA	SYSTEM	SERIES	FORMATION	PREVAILING LITHOLOGY
CENOZOIC	Quaternary	Recent	Alluvial, swamp and beach	Sand, mud, muck and peat
		Pleistocene	Columbia Group terrace deposits 0-50 ft.	Chiefly sand
	Tertiary	Pliocene	Charlton Form. 0 - 15 ft.	Argillaceous LS and clay
		Miocene	Duplin Marl 10 - 15 ft. Alum Bluff Group 0-150 ft. Chattahoochee Form. 100 ft.	Sandy shell marl, blue mud Sand, SS, Claystone Earthy Limestone
		Oligocene	Vicksburg Group Glendon Form. 0 - 100 ft.	White Limestone under cover Chert bearing sand and gravel
		Eocene in West Ga,	Midway Form. 0-400 ft. Ocala Limestone 300 ft. Claiborne Group 200 ft.	Soft white LS, red sand fullers earth, claystone sand, clay and marl.
		in East Ga.	Wilcox Form. 0 - 100 ft. Barnwell and McBean Forms.	Laminated sand and clay 0-200 and 80-100 ft.
MESOZOIC	Cretaceous	Upper	Ripley Form. 900 ft. Eutaw Form. 0 - 100 ft. Tuscaloosa Form, 0-400 ft.	Dark gray sand, clay LS in West Coarse white and pink sand and Kaolin in East. Coarse micaeous
	Jurassic of Triassic		Undifferentiated 790 ft. Diabase and Gabbro Dikes	sand and gravel. Dark gray or black diabase, much jointed and weathered.
PALEOZOIC	Carboniferous	Permian (?)	Granites and Pegmatites	Massive light gray biotite granite lenses, muscovite - biotite granite
		Penn.	Walden Sandstone 500-1000' Lookout Sandstone 50-550'	Sandy shale, coal, SS SS, Conglomerate and shale.
		Miss.	Pennington Shale 515 ft. Bangor Limestone 500-900' Hartselle Sandstone 50-100' Floyd Shale 0-2000 ft. Fort Payne Chert 0-510 ft	Gray and red shale with SS and L Blue fossil LS, shale Coarse white sandstone. Blue shale grading to LS Banded chert with LS
	Devonian of Carboniferous		Chattanooga Shale 0-100'	Fine black shale

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Fig. 1. Georgia Travertine. A marl quarried near Cuthbert containing marine shell fossils in abundance.

Fig. 2. Lithonia Granite-Gneiss. An altered granite having a highly contorted and banded structure, quarried at Lithonia.

Fig. 3. Verde Antique. A form of Serpentine found near Holly Springs, Cherokee County, shot through with coarse and fine calcite veins.

Fig. 4. Stone Mt. Granite. An even-textured granite obtained from Stone Mountain, having some black tourmaline inclusions.

Fig. 5. Elberton Pink Granite. Sold under the trade name of Sunset Pink Granite and obtained from the same quarry as a gray granite near Elberton. The pink is due to the Feldspar coloring.

Fig. 6. Elberton Blue Granite. Sold under the trade name of Long Blue Granite. A very dense Blue Biotite granite found as boulders near Elberton.

Fig. 7. Elberton Gray Granite. Sold under trade name of Dawn Gray Granite and found in the same quarry as the Sunset Pink Granite. The feldspars in this case is white.

PLATE IV

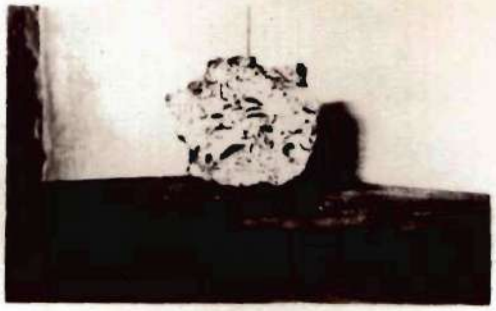


Fig. 1

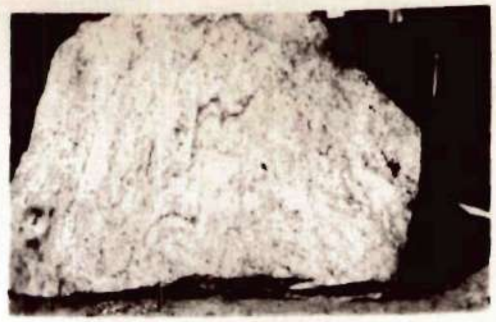


Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

DESCRIPTION OF STONES TESTED

Before entering upon the actual tests it might be well to mention those stones found in Georgia which are being considered. Considering the igneous rocks first, it will be noted on referring to the Map on Page 74b that the granite and granite-gneiss deposits of the state are fairly well distributed throughout the crystalline belt. In each of the quarry areas and within the individual areas the character of the stone varies considerably. For instance the Stone Mountain Granite is of an even texture while the Lithonia granite-gneiss only a few miles distant has a marked banded structure. In the Elberton area within a few miles of each other are obtained three distinct granites differing in color, texture and mode of occurrence. In consideration of this, specimen were obtained from the two areas now producing stone in commercial quantities for test purposes. The stones used are Stone Mountain Granite, Elberton Sunset Pink, Dawn Grey and the Long Blue which took first prize for granites at the St. Louis World's Fair.

As there are no sandstones quarried in Georgia for building purposes, none of the deposits was considered. At first it was thought that specimen of Chickamauga Limestone could be used, but as the quarries have been closed for the last 20 years and the only specimen obtainable was extremely cherty, it had to be passed over for economic reasons. As this was the only limestone ever exploited for building stone in the state, there will be none included in the report.

Of the marbles through the courtesy of the Georgia Marble Company, specimen of the Georgia White, the Etowah and the Creole marbles were obtained. Of the stones used for interior trim this report includes that variety of serpentine known as Verde Antique, and that marl known as Georgia Travertine. Work was also done on the Roman Travertine for comparative purposes. Through the aid of the State Geology Department samples were obtained of both the Rockmart and Fairmont slates. For quite a while these quarries have been closed, but both have economic possibilities for successful operation.

IGNEOUS ROCK

Considering the Igneous stones Watson did considerable work on the granites and gneisses of Georgia in regard to their weathering from a chemical standpoint. The following is from his report[1], on the Blue Granites from the Oglesby area near Elberton: "The fresh unaltered granite is massive, of fine-granular construction, dark

1. Georgia Geological Survey, Bulletin 9-A, Granites and Gneisses of Georgia, Watson; p. 298

blue grey in color showing an admixture of fine-grained quartz, feldspars and bitotite to the unaided eye. The principal minerals are quartz, feldspars, plagioclase and olgioclase, brown biotite, some muscovite, and a little apatite, zircon and magnetite.

"The quartz is frequently intergrown with the feldspar, in the form of rounded ovals or disks of micropegmatic structure clearly indicating contemporaneous growth of the two crystals. It is sometimes enclosed as drop-like inclusions in many of the larger feldspar crystals. The larger individuals further show numerous lines of fracture and undulatory extinction.

"The potash feldspars usually show good cleavages; are intergrown with a second feldspar, albite, as microperthite; and are commonly twined according to the Carlsbad Law. The presence of considerable soda in the analyses corroborates the inference that feldspar, intergrown with the potash species, is albite. The microcline varies in quantity, but it may equal or even exceed the orthoclase in a few sections. The plagioclase is inferior in amount to the potash feldspars, and as a rule, it offers low extinction angles in basal sections, indicating an acid feldspar near olgioclase. This inference is corroborated by the percentage of lime shown in the analyses. The biotite is a deep brown in color and strongly pleochroic. It presents itself in irregular shreds and elongated plates with good crystal outlines, and is intimately associated with muscovite when present. The muscovite varies in quantity and is always less than the biotite. The remaining microscopic assessories show the usual characteristic features.

"The first decided change in this rock on weathering that is perceptible is when it takes on a hard, dull greyish color tinged with from a faint to a highly ferruginous rusty brown color. The rock loses it compact, close-grained structure and takes on a spongy, loose-grained appearance in which the individual mineral grains separate from each other. The feldspars are of a white color, perfectly opaque to the naked eye, and have commenced to split along their cleavage planes. The biotite appears rather leached from hydration and oxidation while the adjacent areas have been stained by a brown tinge due to the iron sequi-oxide resulting from the changing of the biotite."

Watson ran chemical analyses on the fresh rock and the weathered rock, and also separated the weathered minerals from each other. By the use of a magnet fresh particles of magnetite were separated. Washing with cold water yielded various sized particles of the fresh silicates. Digestion with hydrochloric acid at 212° F. showed slight discoloration from the iron oxide present indicating only slight chemical action accompanying the change. The biotite on examination indicated slight decomposition as shown by transparency around the edges of the shreds. The feldspars were coated with a dull white film of supposed Kaolin. However, the percentage of clay in the weathered rock was limited indicating very slow decomposition of the rock.

The above transition continues until the original granite becomes crumbly, highly oxidized, taking on a red color, and is eroded and moved by water action to the rivers and then to the ocean where it is redeposited possibly to form what will be many years from now both a shale and a sandstone. This is a long process but one which is inevitable. As the earth's surface is base-leveled; i.e., the surface eroded down nearly flat, structural stresses are set up in the earth's crust due to an unbalanced condition and those off shore deposits rise again as mountain chains. The most recent of these young mountains are those ringing the Pacific Ocean where there are still many volcanoes, hot springs, geysers and other evidences of recent geologic origin.

The following table is the result of Watson's work on that Biotite granite represented in this report by Long Blue Granite from Elbert County. This particular biotite granite is found as a boulder deposit and is used mainly for monumental work.

Col. 1. Constituents Col. 2. % in Fresh Rock Col. 3. % in Decomposed Rock Col. 4. % in partially decomposed Rock Col. 2', 3' and 4' recalculated on basis of 100 for col. 2, 3 and 4

1	2	3	4	2'	3'	4'
SiO_2 . .	69.74	60.94	67.92	69.15	60.38	67.59
Al_2O_3 . .	16.72	23.39	17.55	16.58	23.08	17.47
Fe_2O_3 . . .	1.45	2.44	1.53	1.44	2.42	1.52
CaO . . .	1.93	0.04	0.99	1.91	0.04	0.98
MgO . . .	0.36	0.43	0.32	0.36	0.42	0.32
Na_2O . . .	4.84	2.18	3.57	4.80	2.16	3.55
K_2O . . .	5.33	3.57	5.43	5.29	3.54	5.41
Ignition	0.47	8.03	3.17	0.47	7.96	3.16
Total	100.84	100.92	100.48	100.00	100.00	100.00

Although physical agencies seem to exert the most force in starting the weathering of rocks, it is the chemical changes which carry the disintergration to completion. These are principally hydration, oxidation and solution in which the most soluble constituents are removed leaving highly ferruginous, gritty clay.

Watson by taking a weighed portion of the finely powdered fresh granite, digested for three hours in 100 cc. of half normal hydrochloric acid at the temperature of boiling water, determined the amount of soluble matter and analyzed it. His results for this Blue Biotite Granite were:

Al_2O_3 . Fe_2O_3	4.05
CaO	0.53
MgO	trace
Na_2O	0.57
K_2O	1.07
Undetermined	4.34
Total Soluble . .	10.56

ELBERTON GREY GRANITE

To the east and roughly parallel to the Blue Biotite Granite belt is found a belt of light grey biotite granite. This granite seems to grade from the blue to the grey and has a coarser grain although the mineral and chemical content is very similar. In the quarry picked to represent this area the granite is a very light grey and differs from the surrounding territory inasmuch as this grey granite grades into a pink granite due to a difference in the color of the feldspars. There is only about thirty yards of the transitional stone which has neither color separating the two. The two granites are exactly similar except for this difference in color. They differ from the Blue Biotite Granite in that the grain is coarser, the biotite occurs in larger flakes although not as thickly distributed as in the former, and the stone does not appear to be as dense as the Blue Granite.

By microscopic analysis, Watson found quartz, the potash feldspars, orthoclase and microcline with considerable microperthitic structure, soda lime feldspar, near oligoclase and biotite, with some intergrown foils of muscovite. Prismatic inclusions of apatite and zircon, and a few scattered grains of magnetite were also found, and in addition chlorite and epidote occurring as secondary products from the alteration of the feldspars and biotite present.

On examination of a partially decayed specimen, it was found that the rock had a pronounced yellow cast and the principal minerals, quarts, feldspar and biotite appeared fresh to the naked eye although the structure was crumbly enough to allow the magnetite present to be separated by the use of a magnet. The amount of clay present was not excessive.

The following table is a summary of tests on Elberton Dawn Grey Granite:

Col. 1. Constituents Col. 2. % in Fresh Rock
Col 3. % in Decayed Rock Col. 4. Soil 2' down
Col. 2'. 2 on 100 basis Col. 3'. 3 on 100 basis

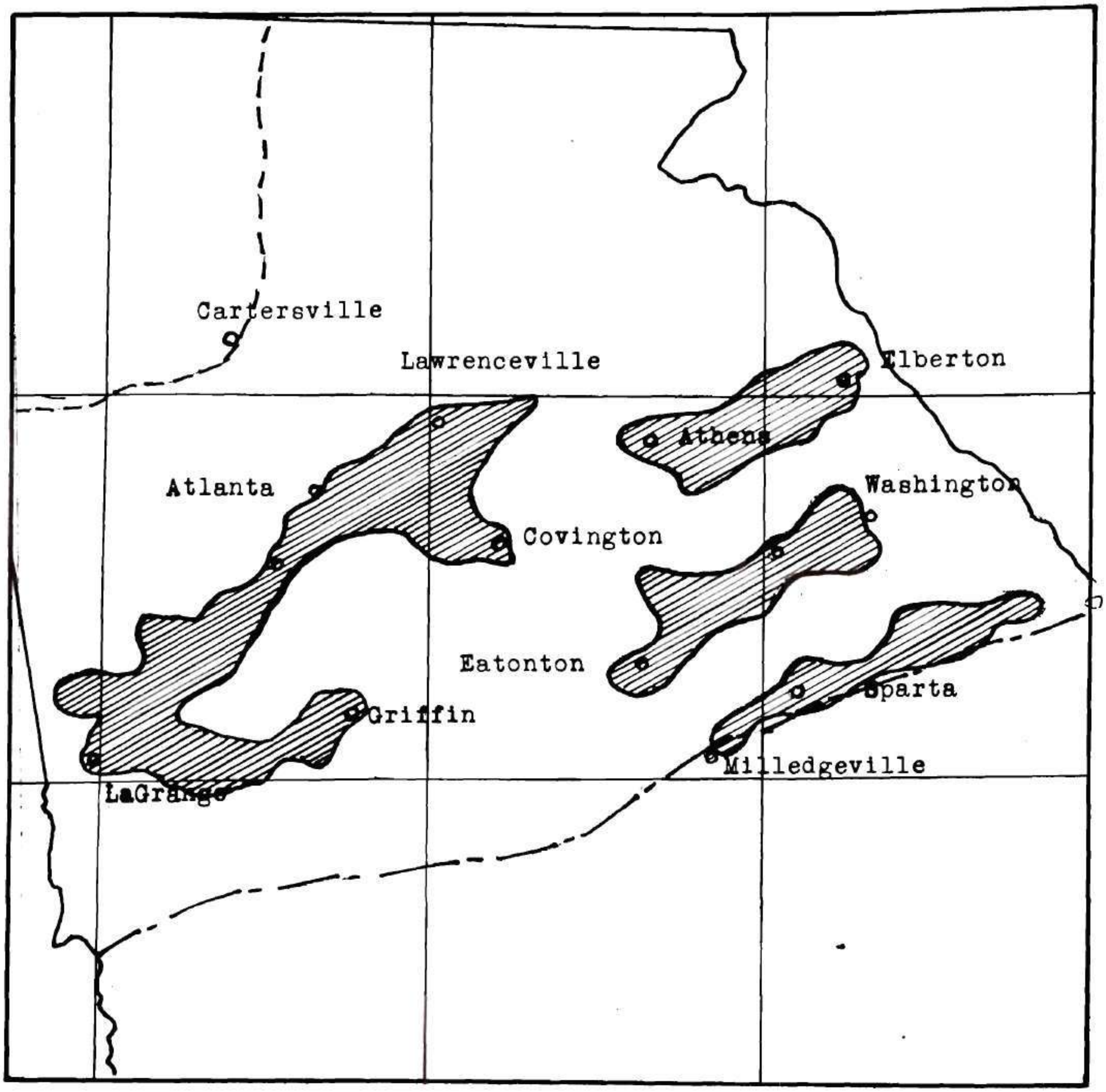
1	2	3	4	2'	3'
SiO_2 . .	69.45	69.00	73.90	70.12	69.17
Al_2O_3. .	15.93	17.31	13.78	16.08	17.35
Fe_2O_3. .	1.31	1.31	1.23	1.32	1.32
CaO . .	1.91	1.18	0.53	1.93	1.18
MgO . .	0.55	0.42	0.05	0.56	0.42
Na_2O . .	4.33	4.00	2.92	4.37	4.01
K_2O . .	5.16	4.74	5.43	5.21	4.75
Ignition	0.40	1.79	2.60	0.41	1.80
Total	99.04	99.75	100.44	100.00	100.00

On being digested in hydrochloric acid of half normal strength for three hours at 212° F. a powdered sample of fresh rock gave the following percentage of soluble matter:

Al_2O_3	3.69
CaO	0.26
MgO	trace
Na_2O	0.29
K_2O	1.06
Undetermined.	3.94
Soluble	9.20

It is interesting to note in connection with the Elberton granites that the Lexington area granites which are a continuation of the granite belt found in the Elberton area, show practically the same physical and chemical characteristics as do the Elberton granites, denoting contemporaneous formation.

PLATE V



DISTRIBUTION OF THE GRANITES AND GNEISSES OF GEORGIA

After Thomas L. Watson

Legend :

Granite and Granite-Gneiss

Southern Fall Line

Cartersville Fault

STONE MOUNTAIN GRANITE

This granite obtained from that granite boss in DeKalb County some 16 miles from Atlanta is remarkably uniform in color, texture and composition. It is a light grey colored granite having a salt and pepper texture in which the constituent minerals, quartz, feldspar and the micas, muscovite and biotite are readily recognized by the unaided eye. Free sulfides and oxides of iron are very rare. Throughout the rock occur Boron spots, whitish lenticular and rounded areas including groups of jet-black tourmaline. However, due to the weathering stability of this mineral it is not a detriment, and serves to break the sameness of the general color.

Quoting from Bulletin 9-A, Georgia Geological Survey[1]: "Microscopically, the rock is a medium-grained, allotriomorphic-granular granite, composed of an aggregate of complexly interlocking quartz and feldspar grains, with numerous grouped plates and shreds of muscovite and some biotite. The quartz is of the usual granite kind, irregular in outline, and displays evidence of some stress in wavy extinction and lines of fracture. The feldspar constituent consists of irregular, varying sized crystals of orthoclase with microperthitic structure; microcline,

1. The Granite and Gneisses of Georgia, Watson; p. 116

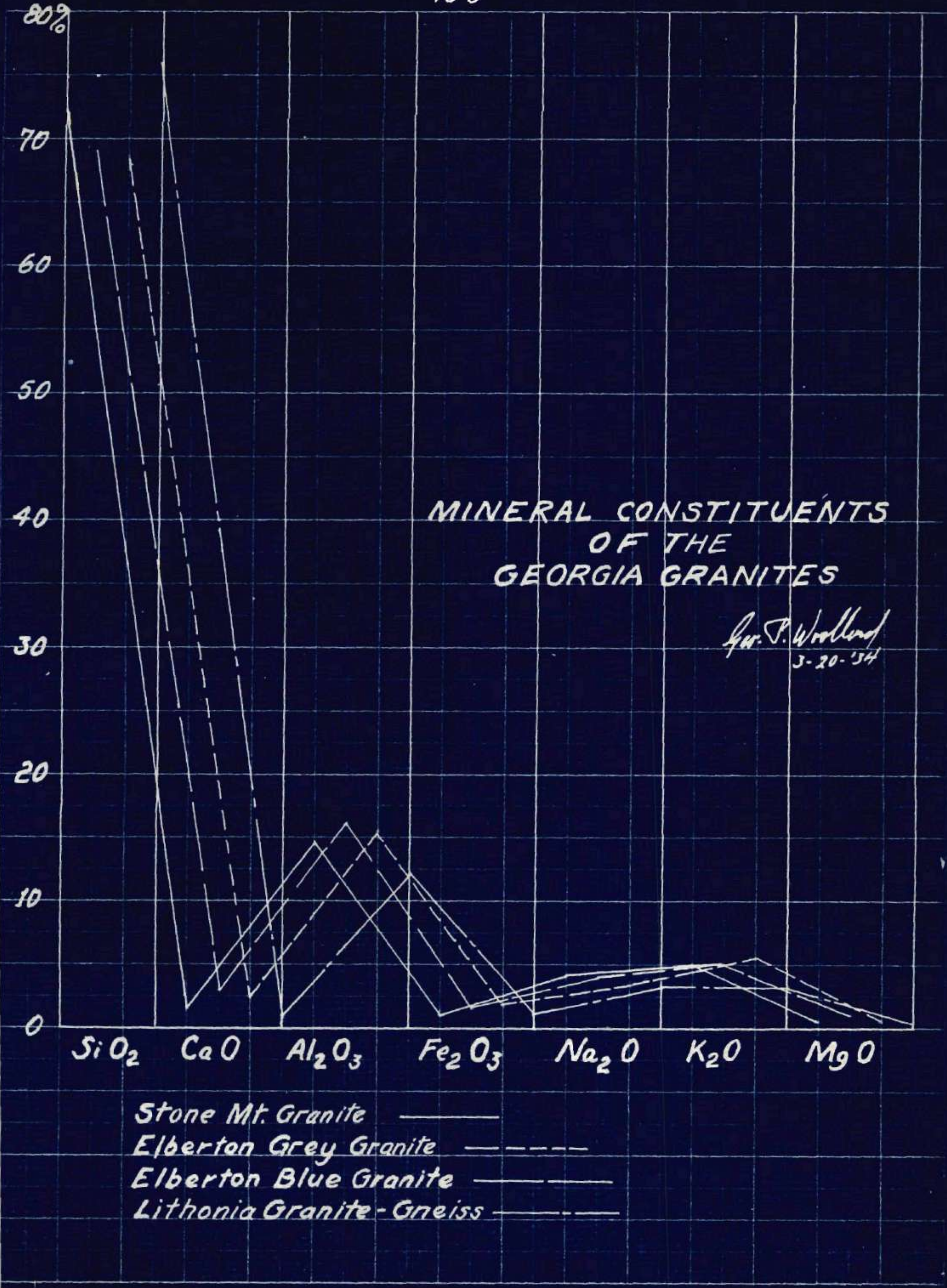
the larger grains of which show some tendency to tabular habit, and scattered, lath-shapped individuals of polysynthetically twined plagioclase. The orthoclase usually shows good cleavage, while the microcline exhibits, in a typical degree, the characteristic gridiron or grating structure. The plabioclase individuals give small extinction angles measured on the twining plane, in basal sections, which indicates a feldspar near oligoclase. The larger feldspar individuals generally contain rounded drop-like inclusions of quartz and other feldspar species. Muscovite is the predominating accessory present. It occurs for the most part, as grouped shreds, with good basal cleavage and strong double refraction, and always appears perfectly fresh. Biotite is more sparingly present as single shreds and filaments with marked basal cleavage, deep color and strong absorption partially altered in some cases, to a reddish brown chlorite. The biotite shows a tendency to seggregate into small bunches, in places. A part of the muscovite is of secondary origin, derived from feldspathic decomposition. Prismatic inclusions of apatite and zircon complete the list of minerals present in the rock."

The following table gives the chemical composition of the fresh rock and a weathered specimen as prepared by R. L. Packard of the Georgia Geological Survey:

Constituent	Fresh	Weathered
Silica	72.56	71.66
Alumina	14.81	16.05
Iron Oxide	0.94	0.86
Lime	1.19	1.07
Magnesia	0.20	0.17
Soda	4.94	4.66
Potash	5.30	4.92
Ignition	0.70	1.00
Total	100.64	100.39

The above analyses indicates this to be a rather acid granite. The low percentage of lime and the corresponding high percentage of Soda indicating the presence of albite and soda lime feldspar. The low percentage of iron is below that for granites as a whole indicating a very small amount of the accessory mineral, biotite.

The following table shows a graphical representation of the chemical constituents of the granites being considered. For comparative purposes also will be found the average for all the granites found in the state as compiled from data tabulated for individual properties in the State Bulletin 9-A of the Georgia Geological Survey. Also is shown a graphical analysis of the Lithonia Granite-Gneiss since it is so closely related to the granites being of similar origin although now highly metamorphised and much older than the adjacent granites.


80%
70
60
50
40
30
20
10
0
MINERAL CONSTITUENTS
OF THE
GEORGIA GRANITES
Geo. P. Woollard
3-20-'34
SiO_2
CaO
Al_2O_3
Fe_2O_3
Na_2O
K_2O
MgO
Stone Mt. Granite
Elberton Grey Granite
Elberton Blue Granite
Lithonia Granite-Gneiss

From the foregoing graph it is seen that there is very little variation broadly speaking in the mineral constituents of the various Georgia granites under consideration. Likewise, when the analyses of the decomposed rocks are considered there is found a marked similarity in composition.

PER CENT CHANGE IN DECOMPOSED ROCK

Constituent	Elberton Blue	Elberton Grey	Stone Mt.
Si_2O	12.6	0.9	1.4
Al_2O_3	13.9	10.8	8.2
Fe_2O_3	6.8	0.0	8.4
CaO	46.2	0.9	10.0
MgO	11.9	23.8	15.0
Na_2O	54.9	7.6	5.6
K_2O	33.3	15.4	7.2
Ignition	171.0	449.0	43.0

In each case there is found a marked decrease in the soda and potash present. This is due to the weathering of the more soluble feldspars containing these chemicals, and the formation of the secondary mineral, alumina, or kaolin, it will be noted increased in each instance. This alumina, being weak structurally allows the grains of quartz or sillica to be removed by wind and water action accounting for the decrease in each instance of this mineral. The other constituents varied according to the original minerals present. The important changes are the decrease in the quartz as secondary to the changing of the feldspars resulting in the loss of the soluble constituents , lime, potash and soda, and the increase of the alumina content.

MARBLE

The marble at the New York quarries commonly known as Georgia White Marble, is a coarsely crystallized, very white marble. Fresh surfaces appear homogenous and seem to be composed of colorless calcite. Weathered surfaces appear rough and are marked by lines of colorless transparent crystals of tremolite. According to Dr. W. S. Bailey of the University of Illinois whoe made a survey of the Tate Quadrangle in 1928 and whose report is incorporated in State Bulletin No. 43, in certain places the tremolite is light green and appears as thin gray layers in the white marble. Some of the tremolite crystals are over an inch long. Microscopic examintaion shows that the white marble is composed entirely of calcite which contains turbid inclusions of liquids and occasional grains of tremolite. Analysis of this tremolite showed it to be approximately

$Mg_5(CaFe)(SiO_3)_6$. The crystals of calcite are about 2 to 3 mm. in diameter. Occurring along with the calcite and occasional grains of tremolite are found specks of carbon and an occasional grain of apatite.

The Etowah Marble is of a pink to an old rose color. It is crossed with greenish-black veins and mottled sections of grayish color. These veins are supposed to represent the original bedding planes of the marble before it was subjected to extensive diastrophic action. The color is thought to be due to the small amount of $MnCO_3$ it contains as it is the only marble found in the Tate quadrangle containing this mineral. The calcite crystals of which it is almost wholly composed measure 3 to 5 mm. in diameter. They are transparent as in the other marbles, but contain tiny inclusions of liquid, a few minute grains of what appears to be hematite or carbon, an occasional large inclusion of hematite, occasional grains of quartz and small crystals of apatite. The dark layers contain in addition to the calcite present, grains of biotite, green epidote, much of which is policilitic, a few flakes of phlogopite and an occasional grain of zircon and quartz. Most of the epidote and biotite occurs between calcite grains and is abundant near the contact of the pink and dark areas.

The Creole Marble differs from all the other types of Marble in the Tate Quadrangle in its dark tone. The interlacing of the dark streaks through the white background is due to the close folding of alternating thin beds of Limestone, some containing carbonaceous material, and others devoid of this constituent. This variety is a little closer-grained than the other two marbles being considered, and consists mostly of twined calcite grains from 1.2 to 2 mm. in diameter, a few rounded grains of quartz about 0.2 to 0.4 mm. in diameter, occasional flakes of colorless greenish tremolite and phlogopite about 0.3 mm. in diameter and an occasional granule of carbon. The dark layers are of similar composition containing more carbon and dark phlogopite and green tremolite. In many places the carbon present outlines the grains of calcite.

Analyses of the marbles under consideration by Dr. Edgar Everhart:

Constituent	Ga. White	Etowah	Creole
Moisture	.04	.10	----
CaO	53.08	54.36	55.00
MgO	.80	.47	1.12
FeO	----	----	----
MnO	Tr.	.14	----
CO_2	----	----	----
Al_2O_3	----	----	----
Fe_2O_3	----	.25	.15
Ign.	42.20	43.58	44.16
SO_3	.00	.00	.00
TiO_2	----	Tr.	.00
P_2O_5	.00	.00	.00
Total Soluble	96.12	98.90	100.43

Constituent	Ga. White	Etowah	Creole
Ignition			
Al_2O_3	.55	.21	
Fe_2O_3	.24	.03	
CaO	.31		
MgO	.91		
FeO	---		
MnO	---		
Na_2O	.04	.03	
K_2O	.01	.01	
TiO_2	Tr.	.01	
SO_3	.00	.00	
P_2O_5	.00	.00	
SiO_2	1.75	.68	
Carbon	----	---	
Total Insoluble	3.80	.97	
Total Soluble	96.12	98.90	
Total	99.92	99.87	
Carbonates			
$CaCO_3$	93.9	97.1	97.6
$MgCO_3$	1.7	1.0	2.35
$FeCO_3$	---	----	-----
$MnCO_3$	---	----	-----

SLATE

Dale[1] defines slate as denoting a rock which has more or less perfect cleavage, being thus adapted to commercial uses, and in which the constituent particles, with very few exceptions cannot be distinguished except in thin sections under a microscope. In contradiction to a schist which is a rock that may be of identical chemical character and mineral composition, but is either made up of coarser particles or possesses a wavy structure, or else is marked

1. U. S. Geological Survey, Bulletin No. 586, Dale; p. 220

by both of these features. Both slates and schists may have originated in deposits of identical character, but may have undergone different processes.

Slates are classified as to origin as sedimentary and igneous. According to structure the slates of sedimentary origin are divided into clay slates and mica slates, and the latter into fading or unfading. A clay is one in which the component minerals have been consolidated by pressure and cemented by carbonates, kaolin or limonite without the development of new minerals. Their fissibility, strength and elasticity are low. In the mica slates a considerable part of the potash and soda bearing minerals have recrystallized under pressure into mica, forming a fabric of scales in parallel dimensional arrangement, and showing aggregate polarization under the microscope in thin sections perpendicular to the cleavage. Those slates showing only slight polarization of the aggregate particles are generally classed as clay slates. The fading or unfading quality of slate depends chiefly on the percentage of iron carbonate present which discolors on exposure to atmospheric conditions.

Dale classified the slates as follows:

I. Aqueous sedimentary
   A. Clay slates. Matrix without any or with very faint aggregate polarization.

B. Mica Slates. Matrix with marked aggregate polarization

1. Fading, with sufficient $FeCO_3$ to discolor considerably on prolonged exposure

   a. Carbonaceous or graphitic
   b. Chloritic (greenish)
   c. Hematitic and chloritic (purplish)

2. Unfading, without sufficient $FeCO_3$ to produce any but very slight discolorization on prolonged exposure.
   a. Graphitic
   b. Henatitic (reddish)
   c. Chloritic (greenish)
   d. Hematitic and chloritic (purplish)
   e. Hematitic, specular and graphitic (bluish-black)

II. Igneous

A. Ash Slates

B. Dike Slates

All of the Georgia slates come under the head of Mica slates of sedimentary origin. The slates from the Rockmart District and the green slates are slightly fading, but the silver gray, high potash slate from the Cartersville District is unfading.

Although the texture of slate is so fine that it has to be studied in thin sections under the microscope, it affects the appearance of the slate. The Georgia green slates have a fine lenticular texture giving them a smooth and slightly lustrous cleavage. Many of the slates though from this belt contain large crystals of chlorite in comparison with the mica crystals, and due to their orientation produce small elevations and depressions on the cleavage surfaces. The Rockmart slates are made up of mineral grains which are on the average much coarser than those of the green slates and the silver grey slates, and in addition they have a strongly marked lenticular texture although the size of the lenses varies with different slates from different quarries. Generally, the lenses are flattened and elongated parallel to the cleavage which crosses the bedding ribbons at an angle. They are made up of masses of crystals of quartz, feldspar, or irregularly oriented sericite flakes. This sericite is evidently due to the alteration of the feldspar, around which the bands of mica and carbonaceous matter bend. Some of the lenses are as large as 1 by 0.25 mm. although the average size is much smaller. This texture produces a cleavage which is good and straight, but lusterless and rough.

In this report the green slates from the Conasauga, and the gray slates from the Rockmart formations are considered. The following table prepared by H. K. Shearer[1] shows the composition.

1. Geological Survey, Georgia Bulletin 34, Shearer; p. 17

Constituent	N. Y., Ver., Penn. Slates	Rockmart Gray Fresh	Rockmart Gray Weathered	Conasauga Green
SiO_2	61.51	56.74	62.40	55.39
Al_2O_3	15.39	17.65	19.74	21.15
Fe_2O_3	2.21	1.10	5.38	1.58
FeO	3.34	4.58	1.00	5.64
MgO	3.23	2.89	1.22	2.55
CaO	1.47	3.18	.05	1.64
Na_2O	1.22	1.66	1.02	1.33
K_2O	3.90	3.42	3.07	2.96
Ign. less CO_2	3.53	3.81	4.98	4.83
H_2O	.67	.21	.44	.22
CO_3	1.55	2.64	.00	1.59
TiO_3	.75	.94	.89	.74
P_2O_5	....	.08	....	.15
SO_3	....	.18	....	....
S	.22	.68	.06	.31
MnO	....	.02	.03	.06
BaO	....	....	....	....
Total	99.99	99.78	100.28	100.14

MARLS

The use of Georgia Marls for interior trim has been comparatively recent. To the trade that class of stone such as is found in the Fox Theater in Atlanta and in the new First National Bank Building also of Atlanta, and the Atlanta City Hall is known as Georgia Travertine. It is so called since to a slight extent it resembles the Roman Travertine which is used extensively for interior trim in buildings, and which can be seen in the Doctor's Building in Atlanta. However, Ford[1] gives the following, "Travertine is a calcium carbonate deposit formed by springs." Since the Georgia deposits are marine, they

1. Donas Manual of Mineralogy, Ford; p. 87

cannot truly be called travertines, and are actually shell marls.

Although deposits of these marls occur throughout the Claiborne Group and the Wilcox Formation of the late Eocene deposits, the only attempt to work them has been at a point near Cuthbert in Randolph County. Here the Marl is found with the marine shells in great profusion in a semi and totally silicified condition bonded together firmly with a slightly argillaceous carbonate. When sawed into slabs and polished it makes a far more attractive material for trim than the real travertine.

SERPENTINE

The only commercially operated deposit of Serpentine is near Holly Springs in Cherokee County. Quoting McCallie[1], "With the exception of the tendency to schistosity on the weathered outcrops, the stone is massive, breaking as readily in one direction as in another; but at the same time the stone is by no means of uniform mineral composition. One of the most striking physical characteristics is the veined condition which adds greatly to its beauty. There are two systems of veins, minute and large. The latter are sometimes open and interfere with the quarrying but the minute veins

1. Geological Survey Georgia, Bulletin L., McCallie; p. 115

are always closed. The origin of the two systems of veins appear to be quite different. The larger being apparently due to rock movements and the other to cleavage lines of the original mineral. Also the vein fillings are different. In the large veins the filling appears very light in color and seems to be composed of ferruginous dolomite and talc, while in the smaller veins the filling appears to be mainly dark greenish serpentine containing minute granules of magnetite. The mass of the material filling the meshes between the individual veins is chiefly pyroxenite and hornblende, which minerals give to the stone a greenish-grey color often splotched with black. The polished stone shows small occasional crystals of pyrite which on weathering produces a brownish stain. However, as it is used on the whole for interior finish this is no detriment."

PART III

TESTS ON GEORGIA BUILDING STONE

As all laboratory tests are to stimulate actual conditions met with in the field, the difficulty of testing rock for other than crushing and transverse strength can only be comprehended when an attempt is made to duplicate the erosinal cycles of nature in a brief period of time. As rock weathering is both meachanical and chemical no one test can be used in the laboratory to duplicate these conditions. Earlier in this report that quality known as "Durability" was mentioned. Durability was there defined as meaing "endurance." It is the ability of a rock to weather, to resist the action of abrasive, wind-blown sand, the disintegrating action of acid-laden rain water, and the stresses set up due to freezing and thawing, the more acute stresses set up by extreme temperature, the bacterial action of parasitic fungus growths, and that artificial wear and tear to which it is subjected to by man.

As building stone can be divided into two general classes, that used for construction purposes and that used for interior finish and trim, it is easily seen that the requisites of one do not apply to the other. With one strength is of primary importance and with the other it might be color or the ability to take a polish and hold it when subject to commercial cleansing agents.

STRENGTH

As outlined under the Requisites of Building Stones, all material regardless of use must possess sufficient strength to adequately meet the demanded requirements. Strength can be divided into three general classes:

1. Crushing strength
2. Transverse strength
3. Elasticity

CRUSHING STRENGTH

Crushing strength is the ability of a stone to resist a load applied at right angles to the bed on which it is laid. Buckley[1] states that the maximum pressure applied to a stone under most normal building conditions is about 158 pounds per square inch. To support his contention he calculated the stress on one of the base stones of the Washington Monument in Washington, D. C., as being only 314.6 pounds per square inch. This agrees with Watson's estimate that a stone with a compressive stress of 600 pounds per square inch is sufficiently strong for all building purposes.

1. The Granites of Wisconsin, Buckley; p. 38
2. Granites and Gneisses of Georgia, Watson, p. 52

Therefore, it is seen that from a building standpoint there are very few stones that could not be used for construction purposes if the crushing strength were the sole factor to be considered. Most stone shows at least a crushing strength of 5000 pounds per square inch.

Merill[1] gives the following results:

	Maximum	Minimum	Average
Granite, 100 tests	28,000	6,117	17,000
Limestone, 80 tests . . .	25,000	3,550	14,000
Sandstone, 132 tests . . .	20,000	1,149	8,500

The above results are what would be expected if one were to view the three types of stone for the first time and was estimating their strength from their physical characteristics such as weight, density and hardness. From these same characteristics it might be assumed that their durability would vary in the same order as their strength. However, as has been previously mentioned, strength cannot be used as a criterion for durability. A notable instance is the State Capitol Building at Atlanta, Georgia. Here is a limestone that is appearing to be far more durable than the granite although its crushing strength is far less than that of the granite. This instance is cited as considerable controversy was created over what was thought to be an exfoliation of

1. Stones for Building and Decoration, Merill; p. summary

the limestone in choosing the material for a new building recently.

The standard accepted throughout the United States and Canada for testing a stone for crushing strength is a two-inch cube with surfaces as plane and parallel as it is possible to get them. Not all work has been done on this standard as it is sometimes difficult to secure specimen as desired. However, all investigators have used a cube in conducting their work. By thus limiting themselves they have obtained results that can be compared favorably with other work done. In making the tests as conducted for this report it was found to be prohibitive from an economic standpoint to have all specimen of the various stones tested of the two-inch standard but all were cubes and as near standard as could be obtained.

In crushing any speciman it has to be considered as a form of a column or rather a prism in which the bending moment is about the heel. Also, the nature of the material, and the condition of fixation and character of the bearing surfaces have to be considered. Rankine in his investigation of columns found that he could obtain more exact results for design purposes by using the following formula known as Rankine's Column Formula.

$$S = \frac{P/A}{1 \; \frac{1}{\varnothing}\left(\frac{L}{r}\right)^2} \qquad r = \sqrt{I/A}$$

S is crushing strength
P load applied
A area of bearing surface
ϕ constant determined by material and end condition
l length of column
r least radius of gyration
I moment of inertia

The value in Rankine's Formula (l/r) is known as the slenderness ratio and when the material being tested is in cubical form, "r" becomes equal to $b/\sqrt{12}$ from $\sqrt{\frac{1/12\ bd^3}{bd}}$, and since in a cube "b" and "d" are equal to "l", the slenderness ratio becomes $1/\sqrt{12}$ and as the value ϕ is $\frac{1}{4000}$, it is evident that the fraction to be added to 1 is so small that it would make no difference in the final answer if the stress were determined by merely dividing the load applied by the bearing surface. However, this only holds true when the speciman being tested is a cube for that is the only case in which the slenderness ratio is really negligible.

As yet I have no information as to any work being conducted on different sized cubes to determine whether there is any appreciable difference in the unit stresses arrived at despite several authors stating that there is. The Stone Mountain Granite Corporation had a series of tests run at the Watertown Arsenal in 1924 in which both two-inch and three-inch cubes were used in determining the compressive stress, and an average of the results obtained for the two different sized cubes gave practically identical results.

Although it is generally advisable to standardize all conditions for testing, it will be seen by considering the following that it would be practically impossible in the case of stone to have everything so standardized.

The stone should be quarried in the same manner; i.e., with or without the use of dynamite.

The stone should be seasoned under the same conditions and for the same period of time.

The cubes should be prepared by the same mechanical means.

The cubes should be of the same dryness.

The tests should be at uniform temperature.

The pressure should be applied in the same direction with respect to bedding planes, etc.

The bearing surfaces of the cubes should be exactly alike.

The bearing faces of the machine should be of the same material.

The same type testing machine should be used.

On those specimen used on compressive test all surfaces were sawed ones. For methods of check and comparison most of the specimen where the grain was distinguishable were tested on bed; i.e., perpendicularly loaded with reference to the bedding planes, as well as, on edge.

Realizing that field conditions are not comparable with laboratory conditions, several specimen were ecentrically loaded to stimulate what might be called the worse possible conditions to see what the results would be. Other variations were in the use of caps. Most investigators use a thin plaster of paris cap over the bearing surfaces with a sheet of cardboard between the machine-bearing surface and that of the specimen. Others, where sawed surfaces are used merely interpose a thin sheet of blotting paper. Both methods were used in these tests. Parks in his investigation on the building stones of Canada found that the more accurate the bearing surfaces between speciman and the machine, the more accurate the results obtained were. Under the best conditions the first crack observed occurred simultaneously with the ultimate failure. As he could obtain no results that gave a very close check where an interval occurred between the first crack and the ultimate failure, he devoted considerable care to the making of test specimen. Bearing surfaces were made parallel to 1/10 mm. and rendered as plane as possible by rubbing with graded abrasive powders on glass. Likewise, the plates transmitting the load on the machine were especially prepared of case-hardened steel.

The following results taken from his tests on a light brown dolmite from near Hamilton, Ontario, will illustrate the difference in results obtained.

Size of Cube	1st Crack	Ultimate load	Ultimate stress per sq. in
1. 4.181 sq."	41,000#	60,900#	14,586#
2. 4.00	60,000#	73,600#	18,548#
3. 3.696	72,250#	72,250#	19,548#

1. Was crushed between blotting paper and the faces of the heads.

2. Was crushed between blotting paper and improvised pieces of steel.

3. Was crushed between blotting paper and carefully prepared case-hardened steel plates.

The following pages give the results as obtained testing the various stones in compression along with cuts of machines used, and photographs of specimen.

Fig. 1. Hydraulic compression Machine. Capacity 250,000 Lbs. On this machine were broken most of the specimen.

Fig. 2. Riehle Brothers Tension Machine. Capacity 100,000 Lb. This machine was used for the compressive tests on those small specimen of Marl, Travertine and Verde Antique as it is capable of more exact readings than the Hydraulic Compression Machine.

Fig. 3. Typical specimen of marble after failure under compression. The center speciman illustrates the theoretical break, a double cone. This was obtained in the majority of cases.

Fig. 4. Specimen of Marble back row, and Granite, front row after failure in compression.

Fig. 5. Specimen of Stone Mountain and Elberton Granites after failure in compression. Several of these had a tendency to develop a double cone on the bottom half and a single cone fitting between on the top half. None developed a cone and cup as was observed on several of the marble specimen.

PLATE VII

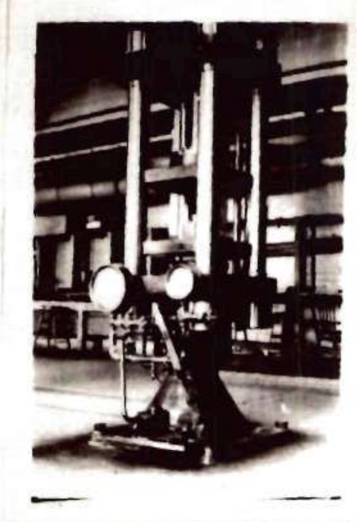


Fig. 1

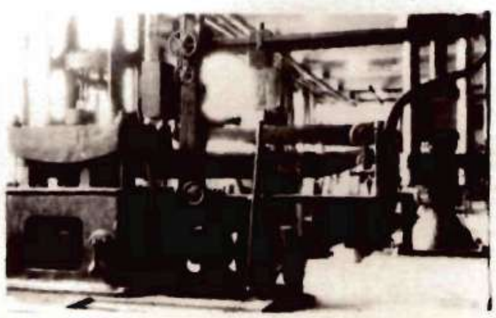


Fig. 2

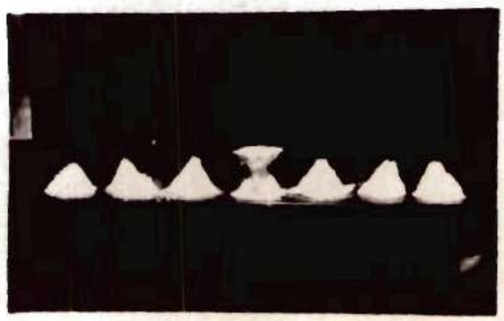


Fig. 3

Fig. 4

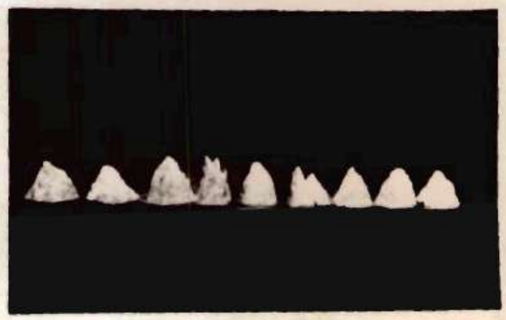


Fig. 5

RESULTS OF CRUSHING TESTS

Machine Used	Ultimate Load Lbs.	Bearing Surface Ins.	Apparent Stress Lbs/Sq In.	Slenderness Ratio	Remarks
	GEORGIA TRAVERTINE (MARL)				
Riehle	14,690	2.00x2.16	3,395	$\sqrt{12}$	
"	7,490	2.05x2.08	1,850	"	Failed on fossil
"	11,850	2.10x2.01	2,840	"	
Hydraulic	14,200	2.00x2.00	3,554	"	All Plaster Paris and Cardboard caps.
Riehle	9,170	1.35x1.36	4,990	"	
"	6,960	1.36x1.36	3,765	"	
"	6,970	1.35x1.36	3,790	"	
	VERDE ANTIQUE (COARSE VEINS)				
Riehle	4,870	1.30x1.30	2,882	$\sqrt{12}$	
"	4,070	1.30x1.32	2,375	"	
"	9,310	1.30x1.30	5,510	"	All PP and C cap
"	3,480	1.30x1.31	2,042	"	
"	2,740	1.26x1.31	1,662	"	Failed on vein
"	8,210	1.26x1.35	4,770	"	
"	6,400	1.29x1.30	3,820	"	
"	6,800	1.27x1.30	4,120	"	
	ITALIAN TRAVERTINE				
Riehle	3,260	1.10x1.15	2,580	$\sqrt{12}$	Very porous
"	3,840	1.06x1.14	3,175	"	
"	8,250	1.10x1.15	6,530	"	All PP and C cap
"	7,850	1.10x1.13	6,320	"	
"	4,450	1.02x1.14	3,820	"	
	GEORGIA WHITE MARBLE				
Riehle	10,900	2.00x2.00	2,725	$\sqrt{12}$	) Eccentric
"	18,030	1.96x1.98	4,650	"	) loading
"	25,440	2.00x1.99	6,400	"	)
Hydraulic	35,200	1.98x2.00	8,880	"	All PP and C cap
"	29,400	1.90x2.00	7,590	"	
"	40,000	2.00x2.00	10,000	"	Blotter cap
	ETOWAH PINK MARBLE				
Riehle	22,910	1.93x1.97	6,030	$\sqrt{12}$	Eccentric Load
Hydraulic	34,000	1.95x1.96	8,890	"	All PP and C cap
"	33,800	2.00x2.00	8,445	"	
"	40,000	1.97x2.00	10,150	"	Blotter cap
"	32,000	1.93x2.00	8,290	"	" "

RESULTS OF CRUSHING TESTS

Machine Used	Ultimate Load Lbs.	Bearing Surface Ins.	Apparent Stress Lbs/Sq In	Slenderness Ratio	Remarks
		CREOLE GRAY MARBLE			
Hydraulic	36,200	2.00x2,00	9,050	$\sqrt{12}$	) Plaster Paris
"	40,000	1.99x2.00	10,060	"	) and cardboard
"	46,400	1.97x1.99	11,790	"	) cap.
"	48,000	1.98x2.00	12,100	"	Blotter cap.
"	29,600	1.98x2.00	7,480	"	Cardboard cap.
		ELBERTON GRAY BIOTITE GRANITE			
Hydraulic	69,600	1.85x2.05	18,380	$\sqrt{12}$	)
"	71,200	2.08x2.00	17,140	"	) PP and C cap.
"	66,400	1.90x2.05	17,060	"	)
		ELBERTON BLUE BIOTITE GRANITE			
Hydraulic	82,000	2.11x2.00	19,460	$\sqrt{12}$	)
"	88,000	2.13x21.6	19,100	"	) PP and C cap.
"	73,000	2.00x2.10	17,790	"	)
"	108,000	2.05x2.05	25,704	"	Blotter cap.
		STONE MOUNTAIN GRANITE			
Hydraulic	59,800	1.94x1.95	15,820	$\sqrt{12}$	) Cont. load
"	58,000	1.90x1.94	15,730	"	) PP and C cap.
"	56,600	1.88x2.04	14,780	"	) on grain
"	35,600	1.62x1.80	12,280	"	) Intrm. load
"	27,800	1.70x1.80	9,080	"	)
"	48,900	1.86x2.04	12,890	"	) PP and C cap
"	35,000	1.70x1.78	11,560	"	)
"	43,400	1.80x2.00	12,020	"	)
"	32,760	1.73x1.77	10,680	"	)
"	66,500	1.75x1.81	21,000	"	) On Bed
"	98,000	1.86x1.94	27,190	"	) Blotter cap.
"	82,000	1.85x1.97	22,500	"	) PP and C cap

DISCUSSION OF RESULTS

The test data is self-explanatory. In explanation of the variation in results as obtained between the screw-type, gear-driven machine and Hydraulic machine, the first tests conducted were with plaster of paris caps on the specimen and the load applied through a rigid head on the machine which gave an eccentric load on the specimen resulting in failure at a far lower point than encountered when an adjustable head was put on the machine. As these results are included merely to show that assuming Watson's maximum figure of 600 pounds per square inch met with in building construction, the stone would even under eccentric loads have a factor of safety of about four and a half.

It will be noted though that with the specimen tested on the hydraulic machine that dispensing with the plaster of paris cap and using only thin blotting paper resulted in an increase of the ultimate stress value obtained. This would tend to indicate that with sawed surfaces it is preferable to not cap the speciman, and gives a direct agreement to Parks' findings regarding the results varying with the bearing-surface conditions.

Unless a speciman contains a fault surface it will tend to break so as to form a single cone or a pair of cones with their apexes at the center of the cube. Buckley[1] when working on the Granites of Wisconsin arrived at the conclusion that these residual forms were indicative of the strength of the material. "Crushing samples with a compressive stress of over 20,000 pounds per square inch generally results in only one pyramid being formed with more of a conical than a pyramidal outline being present. When a stone reaches a crushing strength of over 30,000 pounds per square inch, the breaking results in the production of a single upper cone. Where the strength is below 10,000 pounds per square inch, two well-defined pyramids are formed. Between 10,000 and 20,000 pounds per square inch two pyramids with a more or less conical outline are generally formed."

Where the material was homogenous throughout a close check was obtained on Buckley's observations. With the marbles though, it was found that there existed previous lines of stress as there was a tendency particularly with the Etowah specimen to shear diagonally in failing.

1. The Granites of Wisconsin, Buckley; p. 46

TRANSVERSE STRENGTH

Transverse strength is the ability of a material to withstand a bending strain due to a load when supported as a simple beam.

Although the American Society of Testing Materials in 1929 set tentative standards for this test in which a 1" x $1\frac{1}{2}$" specimen was specified to be dried at 110° C. for 24 hours and tested over a 10" span with load increments of 50 pounds applied at the rate of 100 pounds per minute through a knife edge at the center of span while supported on two knife edges, it was found to be impossible to obtain specimen of the desired size, and as a result the tests were conducted on available specimen with regard to the procedure specified. This should not cause any appreciable difference in results as regards unit stress.

The stress was calculated according to $S = Mc/I$

where S is the unit stress
M is the bending moment under the load
c the distance from the neutral axis to the outermost fiber
I the moment of inertia.

By substituting the values of $M = \frac{1}{4}PL$, $c = d/2$, $I = 1/12\ bd^3$

Where P is the load applied at the center
L is the distance between reactions
d the depth of the speciman
b the width of the speciman

$S = \dfrac{\frac{1}{4}\,Pl\ d/2}{1/12\ b\ d^3} = \dfrac{3PL}{2\ b\ d^2}$ which is the formula given by the Society for Testing Materials.

The following pages give the apparatus used with results obtained.

Fig. 1. Apparatus as set up for the Transverse Test showing a speciman in position.

Fig. 2. Specimen after failure under transverse loading of Verde Antique. The two end specimen on the back row were of a more dense composition with finer calcite veining, and it will be noted fractured at an angle of about 308 to the load.

Fig. 3. Typical failure of Stone Mountain Granite (back row) and Elberton Long Blue Granite under transverse loading.

Fig. 4. Specimen of Marble after failure under transverse loading. First and second row and first on left of the last row are Georgia White Marble. Second on the last row is Etowah Marble. The last on the back row is clouded Cherokee Marble.

Fig. 5. Failure of Travertine specimen under transverse loading. Front row is Georgia Travertine, a marl. The back row is Italian Travertine, a true travertine of spring deposition.

Fig. 6. Failure of Elberton Dawn Gray and Sunset Pink Granite under transverse loading. Both of these granites are from the same quarry, and vary only in color of the feldspars.

PLATE VIII

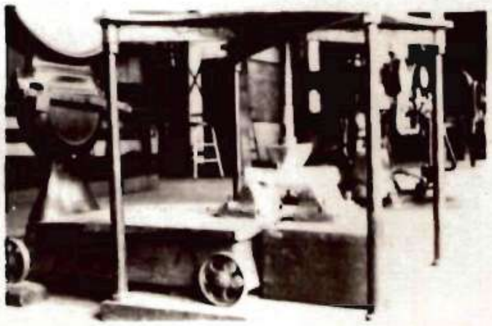


Fig. 1

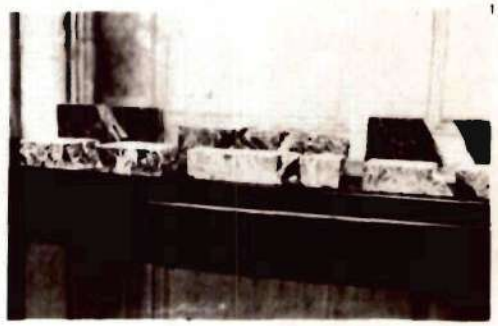


Fig. 2

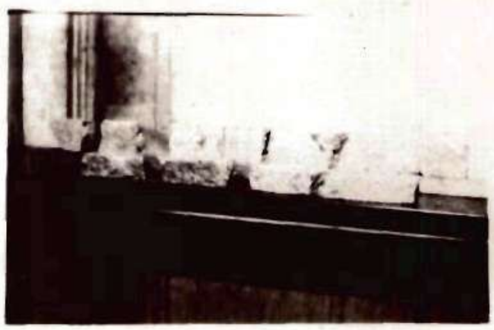


Fig. 3

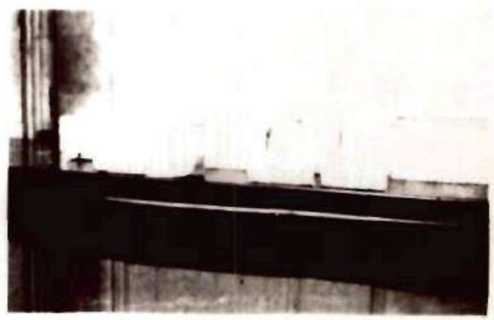


Fig. 4

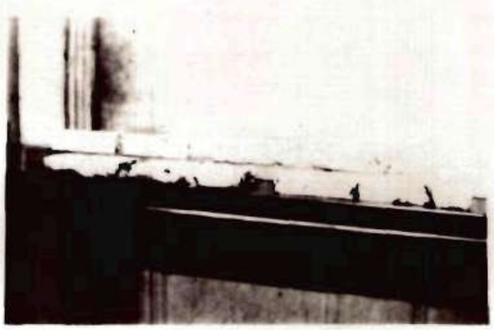


Fig. 5

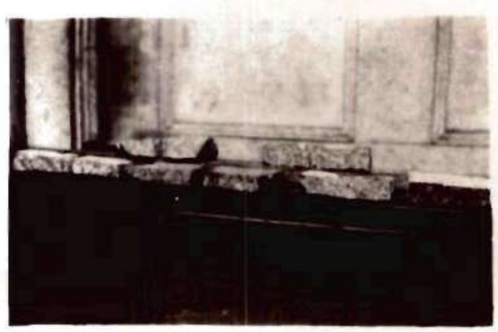


Fig. 6

RESULTS OF TRANSVERSE TESTS

Reaction Load Lbs.	Loading Position	Section Ins.	Span Ins.	Tensile Stress Lbs/Sq.In.	Remarks
	VERDE ANTIQUE (SERPENTINE) (very coarse dolomitic veining)				
190	Flat	1.64x1.30	4	823	
203	"	1.85x1.27	5	1,022	
115	"	2.06x1.30	5	496	Large vein under load
422	"	1.96x1.15	5	2,432	
	(Fine dolomite veining)				
400	Flat	0.97x2.24	4	2,280	
386	"	0.96x2.20	5	2,855	
	ITALIAN TRAVERTINE				
117	Flat	0.7x1.3	6	1,620	
113	"	1.0x2.8	5	605	Fracture on previous diagonal strain line.
	GEORGIA TRAVERTINE (MARL)				
80	Flat	0.70x2.20	6	1,340	
36	"	0.70x2.15	6	548	Failed on fossil
122	"	0.70x2.24	4	1,332	
98	"	0.75x2.15	4	974	
	GEORGIA WHITE MARBLE				
184	Flat	1.32x1.50	6	1,309	
79	"	1.25x1.50	6	606	
190	"	1.00x2.00	6	1,710	
280	"	1.22x1.48	4	1,530	
260	"	1.22x1.48	4	1,418	
139	Edge	1.25x1.48	9	686	
	ETOWAH PINK MARBLE				
209	Flat	1.00x2.00	6	1,881	
	CREOLE MARBLE				
146	Flat	1.00x2.00	6	1,461	

RESULTS OF TRANSVERSE TESTS

Reaction Load Pounds	Loading Position	Section Ins.	Span Ins.	Tensile Stress Lbs/Sq.In.	Remarks
		ELBERTON BLUE BIOTITE GRANITE			
565	Flat	1.05x2.25	5	3,418	
330	"	0.96x2.25	5	2,383	
		ELBERTON PINK GRANITE			
218	Flat	0.72x2.40	5	2,622	
		ELBERTON GREY GRANITE			
246	Flat	0.75x2.15	4	2,443	
384	"	1.00x2.10	4	2,480	
250	"	0.85x1.90	5	2,738	
463	Edge	1.10x1.35	4	2,775	
		STONE MOUNTAIN GRANITE			
123	Flat	0.92x1.90	6	1,365	
240	"	0.90x1.80	3	1,485	
260	"	0.85x1.92	3	1,685	
855	Edge	1.05x1.86	3	2,120	
	T..	GREY ROCKMART SLATE			
80	Flat	.255x4.5	12	4,920	
70	"	.245x4.5	12	4,620	
80	"	.146x4.25	8	10,600	
		GREEN FAIRMONT SLATE			
108	Flat	.262x4.60	12	6,160	
68	"	.1863x4.6	12	7,650	
80	"	.212x3.25	8	6,580	

T.. Loads recorded for slates are total loads.

DISCUSSION OF RESULTS

Although all previous work on the transverse strength of the stones under consideration has been limited to the marbles and the slates, the results appear to be uniformly satisfactory, and bear the same relationship that was indicated by the results of the crushing tests.

On comparing results as determined on Georgia White Marble with the findings made by the Bureay of Standards in 1919 there was found to be a much higher average. The results of tests as conducted by the Bureau of Standards gave values ranging from 1290-1412 pounds per square inch whereas the present values obtained ran to 1710. Likewise, a test of the Etowash Marble showed a value of 1881 pounds per square inch whereas the maximum value obtained by the Bureau of Standards was 1606 pounds per square inch for this marble. However, on testing the Creole Marble the author's value showed 1,461 pounds per square inch which is about the average value obtained by the Bureau of Standards. Their results ranged from 1320-1536 pounds per square inch.

The only other comparison was on the Rockmart Slates. The average of two tests made in 1917 by the Bureau of Standards showed a value of 7,589 pounds per square inch which is about an average value as obtained from present tests which ranged from 4,620-10,060 pounds per square inch.

MODULUS OF ELASTICITY

When any material is subject to a load either in compression or flexure, there is an observed deformation of material. If the material is resilient, it will assume its original condition on removal of the load, and within certain limits all material will do this. The limiting factor is the load which can be applied beyond which the material will not return to its original condition. This point is called the elastic limit. Hooke's Law states that within the Elastic limit the stress in a material is directly proportional to the strain. In other words there exists a straight line ratio between stress and strain up to the elastic limit. Therefore, for design work the strength of a material is always considered as maximum at the elastic limit, for any loads in excess of that value would result in a deformation of the material that would be permanent even if the load were immediately removed.

The Modulus of Elasticity of a material is the ratio of Stress to Strain within the elastic limit. If Stress were plotted against Strain using rectangular axes, the Modulus of Elasticity would be the tangent of the angle formed with the absciaae, or the slope of the line up to the elastic limit.

For determining the Modulus of Elasticity $E = \frac{S}{e}$ where S is the unit stress as determined either for compression or flexure; i.e., Compression $S = \frac{P}{a}$ Transverse $S = \frac{3\ PL}{2\ b\ d^2}$, e is unit strain and in compression equals f/L in flexure $e = \frac{6\ d\ f}{L^2}$

f is observed deformation
d is depth of specimen
L is free height on specimen in compression and span of specimen in flexure.

Serial No. 56

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST-Compression

TESTED BY: Hydraulic Machine, Plaster Paris cap and cardboard, Geo. P. Woollard

Date Dec. 26, 1933 Exp't No. 2

Kind of Material Stone Mt. Granite

Original Length 2.01" Final Length

Dia. inches { Original 1.8"x1.7" Final } Area, Sq. inches { Original Final }

Modulus of Resilience Load per Sq. In. at Elastic Limit

Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %

Yield Point, lb. per sq. in. Form of Section Elongation %

Reading No.	LOAD		EXTENSOMETER READINGS				ELONGATION		Modulus of Elasticity
	Actual	Per Sq. Inch	Left	Right	Mean	Difference	Actual	Per Inch	
Units	Lbs.	#/□"	Lateral Expansion		Deflection		Ins.	"/"	
	0	0	1.70"	1.85"	.461				
	8000	2618			.438	.023	.023	.001143	
	12000	3920			.411	.027	.050	.002482	
	16000	5230	1.7"	1.86"	.403	.008	.058	.00288	
	20000	6530			.390	.013	.071	.00352	
	24000	7840	1.75"	1.90"	.381	.009	.080	.00397	
	27800	9080	1.75"	1.94"	.376	.005	.085	.00425	

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST-Compression

TESTED BY: Hydraulic Machine, Cardboard, Plaster Paris cap, Geo. P. Woollard

Date Dec. 26, 1933 Exp't No. 1

Kind of Material Stone Mt. Granite

Original Length 2.05" Final Length

Dia. inches { Original 1.8"x1.62" Final } Area, Sq. inches { Original Final }

Modulus of Resilience Load per Sq. In. at Elastic Limit

Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %

Yield Point, lb. per sq. in. Form of Section Elongation %

Reading No.	LOAD		[redacted]				ELONGATION		Modulus of Elasticity
	Actual	Per Sq. Inch	Left	Right	Mean	Difference	Actual	Per Inch	
Units	Lbs.	#/□"	Lateral Expansion		Deflection		Ins.	"/"	
	0	0	1.62	1.86	.451				
	8000	2760			.437	.014	.014	.00682	
	10000	3440			.4195	.0175	.0315	.0154	
	12000	4140			.4025	.017	.0485	.0236	
	16000	5520	1.62	1.86	.3865	.016	.0645	.0314	
	20000	6880			.379	.0075	.072	.0351	
	24000	8270			.366	.013	.085	.0415	
	28000	9660			.355	.011	.096	.0468	
	32000	11020	1.63	1.86	.3475	.0075	.1035	.0502	
	35600	12280	1.65	1.94	.320	.0275	.131	.0638	

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST-Compression

TESTED BY: Riehle Machine, Plaster Paris cap and cardboard, Geo. P. Woollard

Date Dec. 27, 1933 Exp't No. 4

Kind of Material Stone Mt Granite

Original Length 1.65" Final Length

Dia. inches { Original 1.70"x1.78" Final } Area, Sq. inches { Original Final }

Modulus of Resilience Load per Sq. In. at Elastic Limit

Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %

Yield Point, lb. per sq. in. Form of Section Elongation %

Reading No.	LOAD		[redacted]				ELONGATION		Modulus of Elasticity
	Actual	Per Sq. Inch	[redacted]	[redacted]	[redacted]	Difference	Actual	Per Inch	
Units	0	#/□"	Lateral Expan. 1.73	1.96	Deft. .210		Ins.	"/"	
	1000	330			.120	.090	.090	.00552	
	2000	660			.116	.004	.094	.00576	
	4000	1320			.104	.012	.106	.00652	
	6000	1980			.090	.014	.120	.00736	
	8000	2640			.077	.013	.133	.00816	
	10000	3300			.060	.017	.150	.00921	
	12000	3960			.052	.008	.158	.0097	
	14000	4620			.046	.006	.164	.01007	
	16000	5280			.041	.005	.169	.01042	
	18000	—			—	—			
	20000	6600			.037	.004	.173	.01062	
	22000	7260			.036	.001	.174	.01068	
	24000	7920			.033	.003	.177	.01086	
	26000	8600			.031	.002	.179	.01099	
	28000	9240			.027	.004	.183	.01123	
	30000	9920	1.78	1.76	.024	.003	.186	.01141	
	32000	10560			.020	.004	.190	.01166	
	35000	11560	1.78	1.86					

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST-Compression

TESTED BY: Riehle Machine, Plaster Paris cap and cardboard, Geo. P. Woollard

Date Dec. 27, 1933 Exp't No. 3

Kind of Material Stone Mt. Granite

Original Length 1.70" Final Length

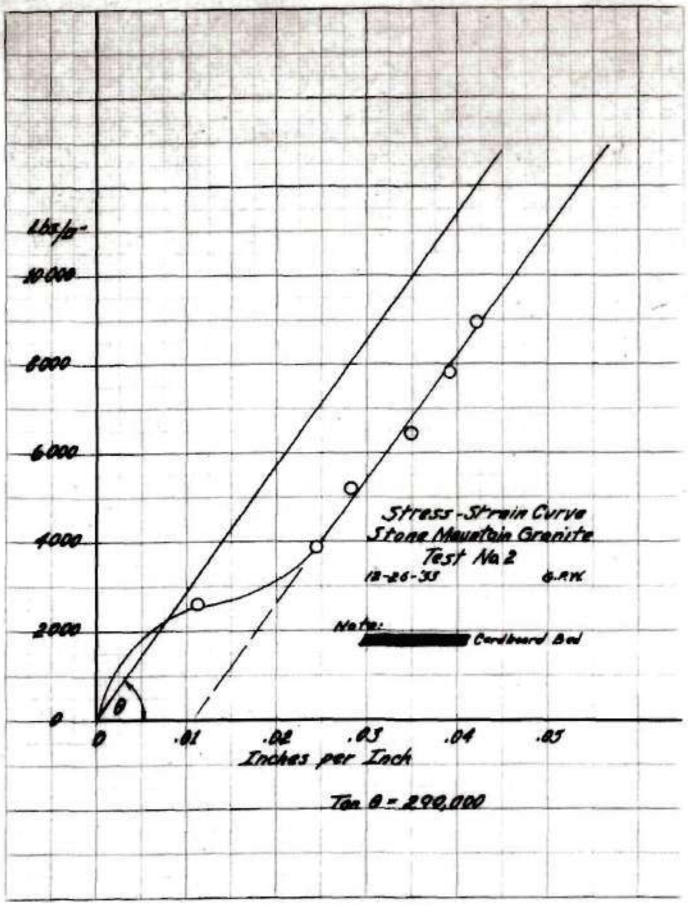
Dia. inches { Original 1.86"x2.04" Final } Area, Sq. inches { Original Final }

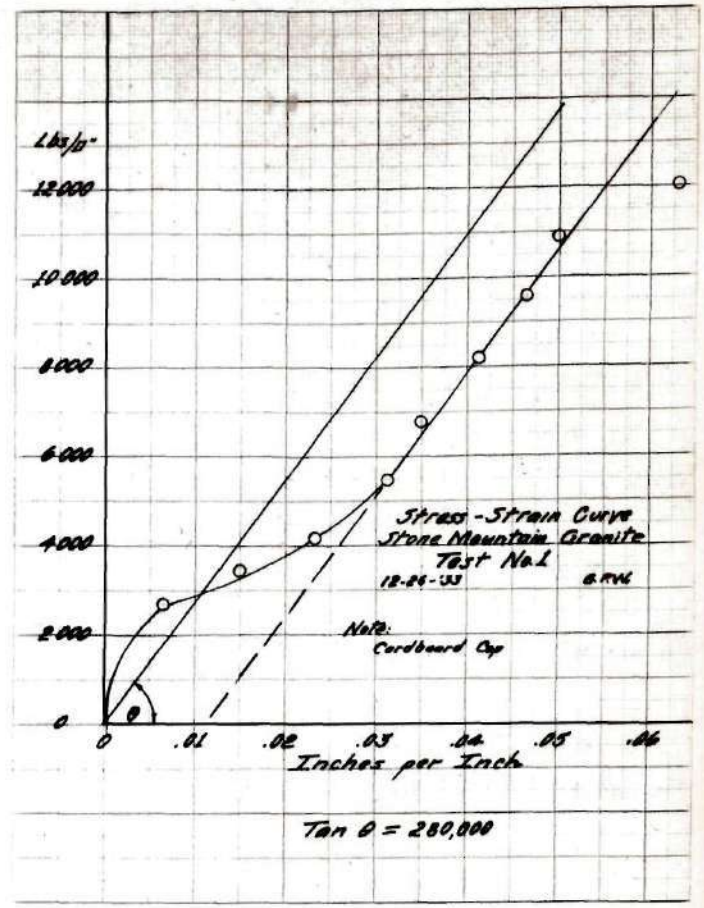
Modulus of Resilience Load per Sq. In. at Elastic Limit

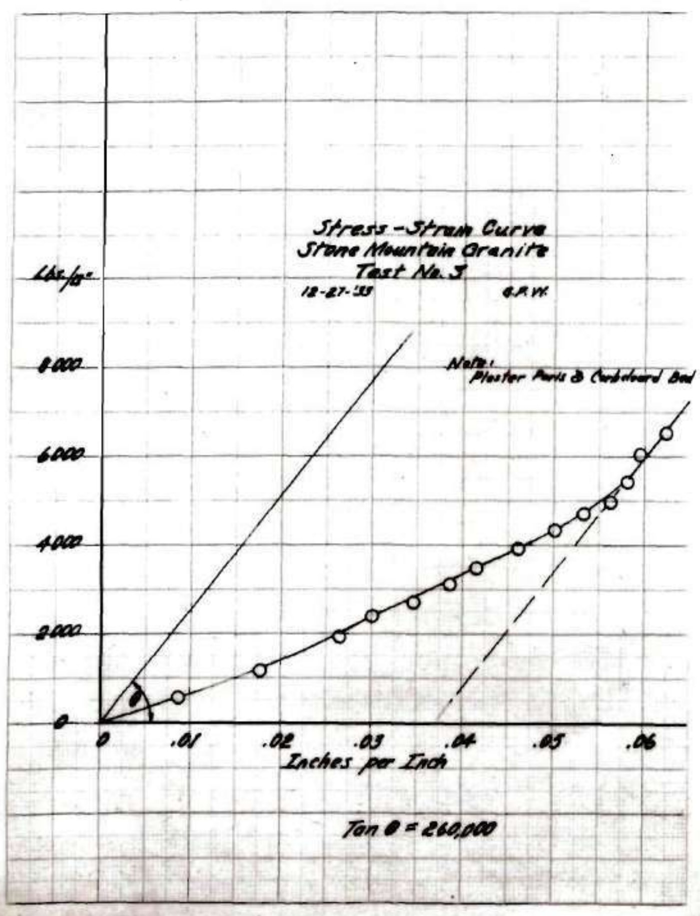
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %

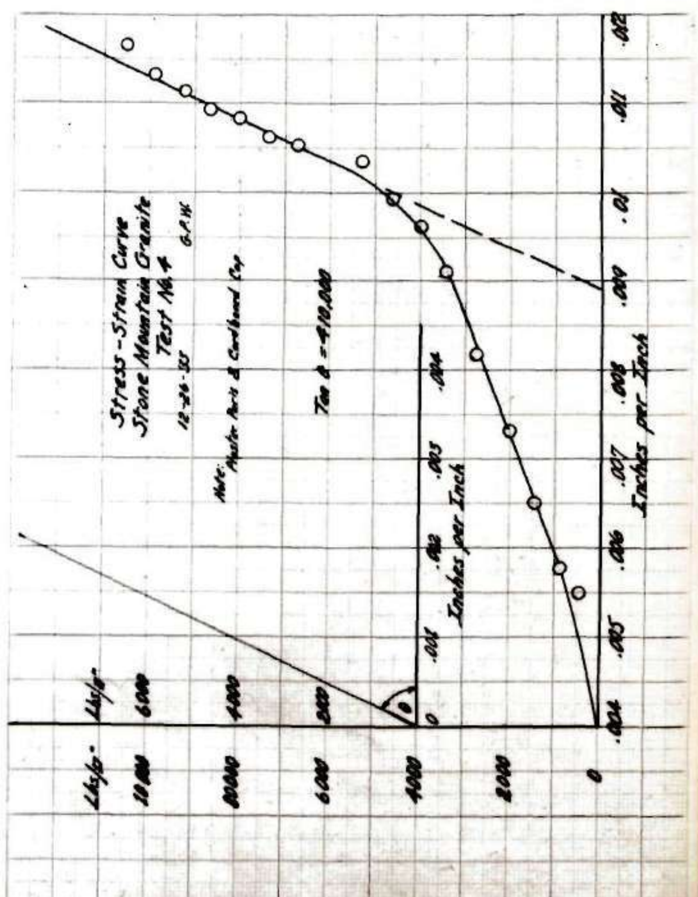
Yield Point, lb. per sq. in. Form of Section Elongation %

Reading No.	LOAD		[redacted]				ELONGATION		Modulus of Elasticity
	Actual	Per Sq. Inch	Left	Right	Mean Deflection	Difference	Actual	Per Inch	
Units	0	#/□"	Lateral Exp. 1.86	2.04	.107				
	1000	264			.092	.015	.015	.00884	
	4000	1056			.077	.015	.030	.01765	
	7000	1845			.060	.017	.047	.0276	
	9000	2375			.0555	.0045	.0515	.0302	
	10000	2640			.048	.0065	.058	.0341	
	12000	3168	1.86	2.04	.040	.008	.066	.0388	
	13000	3422			.0355	.0045	.0705	.0414	
	15000	3950			.027	.0085	.079	.0465	
	16000	4220			.019	.008	.087	.0512	
	18000	4750			.015	.004	.091	.0535	
	19000	5020			.011	.004	.095	.0568	
	21000	5540			.006	.005	.100	.0588	
	23000	6060			.005	.001	.101	.0595	
	25000	6590			.000	.005	.106	.0624	
	37000	9750	1.87	2.06					
	48900	12890	1.97	2.07					


Lbs/□"
10,000
8000
6000
4000
2000
0
Stress-Strain Curve
Stone Mountain Granite
Test No. 2
12-26-33
G.P.W.
Note:
Cardboard Bed
θ
0
.01
.02
.03
.04
.05
Inches per Inch
Tan θ = 290,000


Lbs/□"
12,000
10,000
8000
6000
4000
2000
0
Stress-Strain Curve
Stone Mountain Granite
Test No. 1
12-26-33
G.P.W.
Note:
Cardboard Cap
θ
0
.01
.02
.03
.04
.05
.06
Inches per Inch
Tan θ = 280,000


Stress-Strain Curve
Stone Mountain Granite
Test No. 3
12-27-33
G.P.W.
Lbs/□"
8000
6000
4000
2000
0
Note:
Plaster Paris & Cardboard Bed
θ
0
.01
.02
.03
.04
.05
.06
Inches per Inch
Tan θ = 260,000


Stress-Strain Curve
Stone Mountain Granite
Test No. 4
12-26-33
G.P.W.
Note: Plaster Paris & Cardboard Cap
Tan θ = 410,000
θ
Lbs/□"
6000
4000
2000
0
.001
.002
.003
.004
Inches per Inch
Lbs/□"
10,000
8000
6000
4000
2000
0
.004
.005
.006
.007
.008
.009
.01
.011
.012
Inches per Inch

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING
GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST - Compression

TESTED BY Riehle Machine Plaster Paris cap and cardboard Geo. P. Woollard

Date Dec. 27, 1933 Exp't No. 5
Kind of Material Stone Mt. Granite
Original Length 1.74" Final Length
Dia. inches Original 1.8" x 2.0" Final Area, Sq. inches Original Final
Modulus of Resilience Load per Sq. In. at Elastic Limit
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %
Yield Point, lb. per sq. in. Form of Section Elongation %

Reading No.	LOAD Actual	LOAD Per Sq. Inch	[redacted] Left	Right	Mean	Difference	ELONGATION Actual	ELONGATION Per Inch	Modulus of Elasticity
Units	0	#/□"	Lateral 1.86	Expansion 2.05	Deflection .216		Ins.	"/"	
	1000	276			.215	.003	.003	.00172	
	2000	555			.209	.007	.010	.00574	
	4000	1110	1.86	2.06	.207	.002	.012	.00688	
	6000	1665			.205	.002	.014	.00803	
	8000	2220			.201	.004	.018	.01034	
	10000	2780			.197	.004	.022	.01265	
	12000	3330			.183	.004	.026	.0149	
	14000	3890			.188	.005	.031	.0178	
	16000	4440			.182	.006	.037	.0212	
	18000	5000			.177	.005	.042	.0241	
	20000	5550			.174	.003	.045	.0258	
	22000	6100			.171	.003	.048	.0286	
	24000	6660			.164	.007	.055	.0316	
	26000	7210			.161	.003	.058	.0333	
	28000	7760			.157	.004	.062	.0356	
	30000	8320			.155	.002	.064	.0367	
	32000	8860			.154	.001	.065	.0373	
	34000	9440			.153	.001	.066	.038	
	36000	9980			.152	.001	.066	.038	
	38000	10520	1.86	2.07	.152				
	43400	12020							

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING
GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST - Compression

TESTED BY Riehle Machine Plaster Paris cap and cardboard Geo. P. Woollard

Date Dec. 27, 1933 Exp't No. 6
Kind of Material Stone Mt. Granite
Original Length 1.74" Final Length
Dia. inches Original 1.73" x 1.77" Final Area, Sq. inches Original Final
Modulus of Resilience Load per Sq. In. at Elastic Limit
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %
Yield Point, lb. per sq. in. Form of Section Elongation %

Reading No.	LOAD Actual	LOAD Per Sq. Inch	EXTENSOMETER READINGS Left	Right	Mean	Difference	ELONGATION Actual	ELONGATION Per Inch	Modulus of Elasticity
Units	0	#/□"	.157	.203	.180		Ins.	"/"	
	1000	326	.157	.177	.167	.013	.013	.00748	
	2000	652	.153	.176	.1645	.0025	.0155	.00892	
	4000	1306	.145	.170	.1575	.007	.0225	.01296	
	6000	1958	.140	.166	.153	.0045	.027	.01554	
	8000	2620	.130	.159	.1445	.0085	.0355	.0204	
	10000	3260	.116	.149	.1325	.012	.0475	.0273	
	12000	3920	.110	.140	.125	.0075	.055	.0316	
	14000	4560	.101	.133	.117	.008	.063	.0362	
	16000	5226	.091	.126	.1085	.0085	.0715	.0412	
	18000	5875	.087	.123	.105	.0035	.075	.0432	
	20000	6530	.082	.119	.1005	.0045	.0795	.0457	
	22000	7180	.076	.118	.097	.0035	.083	.0477	
	24000	7840	.073	.115	.094	.003	.086	.0494	
	26000	8500	.068	.111	.0895	.0045	.0905	.0521	
	28000	9150	.062	.110	.086	.0035	.094	.0541	
	30000	9800	.060	.110	.0835	.0025	.0965	.0565	
	32760	10680							
	Lateral Expansion								
0	1.83	1.73							
28000	1.85	1.75							
32760	1.92	1.75							

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING
GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST Compression

TESTED BY Hydraulic Machine Blotting Paper cap Geo. P. Woollard

Date 1-9-34 Exp't No. 8
Kind of Material Stone Mt. Granite
Original Length 1.68" Final Length
Dia. inches Original 1.86" x 1.94" Final Area, Sq. inches Original Final
Modulus of Resilience Load per Sq. In. at Elastic Limit
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %
Yield Point, lb. per sq. in. Form of Section Elongation %

Reading No.	LOAD S Actual	LOAD Per Sq. Inch	EXTENSOMETER READINGS Left	Right	Mean	Difference	ELONGATION Actual	ELONGATION Per Inch	Modulus of Elasticity
Units	Lbs.	#/□"	Inches				Ins.	"/"	
	0	0	.4475	.436	.4427				
	8000	2100	.437	.416	.4265	.0162	.0162	.00965	
	10000	2770	.432	.415	.4235	.003	.0192	.0114	
	12000	3320	.429	.414	.4215	.002	.0212	.0126	
	14000	3880	.427	.413	.420	.0015	.0227	.0135	
	16000	4430	.4257	.411	.4183	.0017	.0244	.0145	
	18000	4980	.423	.411	.4162	.0021	.0265	.0157	
	20000	5540	.422	.410	.416	.0002	.0267	.0159	
	24000	6650	.421	.409	.415	.001	.0277	.0165	
	28000	7760	.419	.407	.413	.002	.0297	.0177	
	32000	8870	.417	.406	.4115	.0015	.0312	.0186	
	40000	11090	.415	.404	.4095	.002	.0332	.0194	
	44000	12190	.413	.403	.408	.0015	.0347	.0207	
	48000	13300	.413	.4025	.4075	.0005	.0352	.0209	
	52000	14410	.412	.402	.407	.0005	.0357	.0212	
	60000	16620	.410	.400	.405	.002	.0377	.0225	
	68000	18830	.409	.399	.404	.001	.0387	.0230	
	72000	19940	.408	.398	.403	.001	.0397	.0237	
	88000	24380	.407	.392	.3995	.0035	.0432	.0257	
	98000	27190							
			Lateral Expansion						
			1.86	1.98					
			1.88	1.98					

Serial No. 58

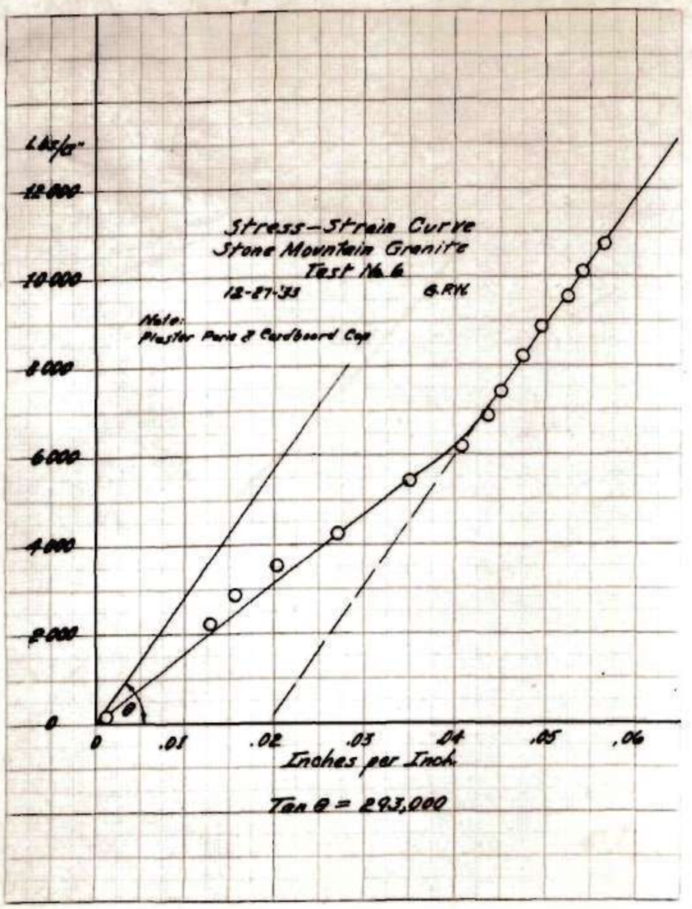
DEPARTMENT OF EXPERIMENTAL ENGINEERING
GEORGIA SCHOOL OF TECHNOLOGY

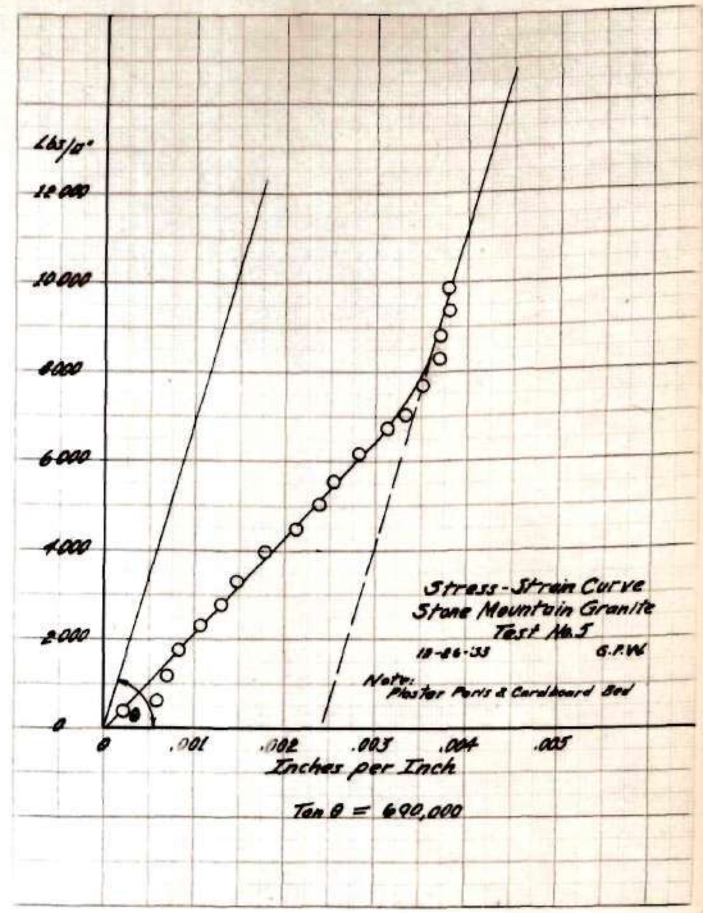
[redacted] TEST - Compression

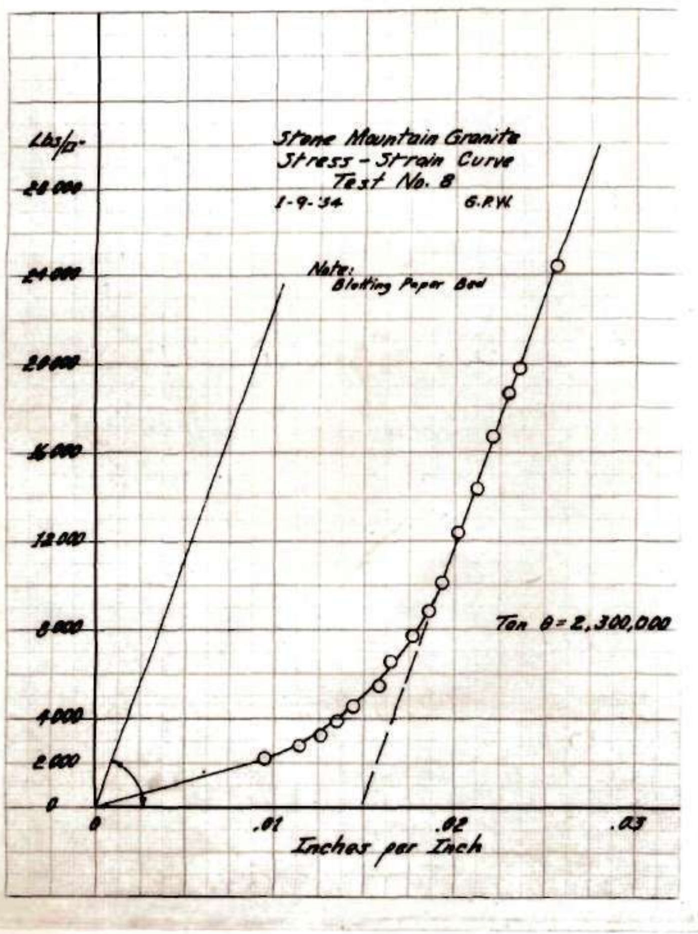
TESTED BY Riehle Machine Blotting Paper cap Geo. P. Woollard

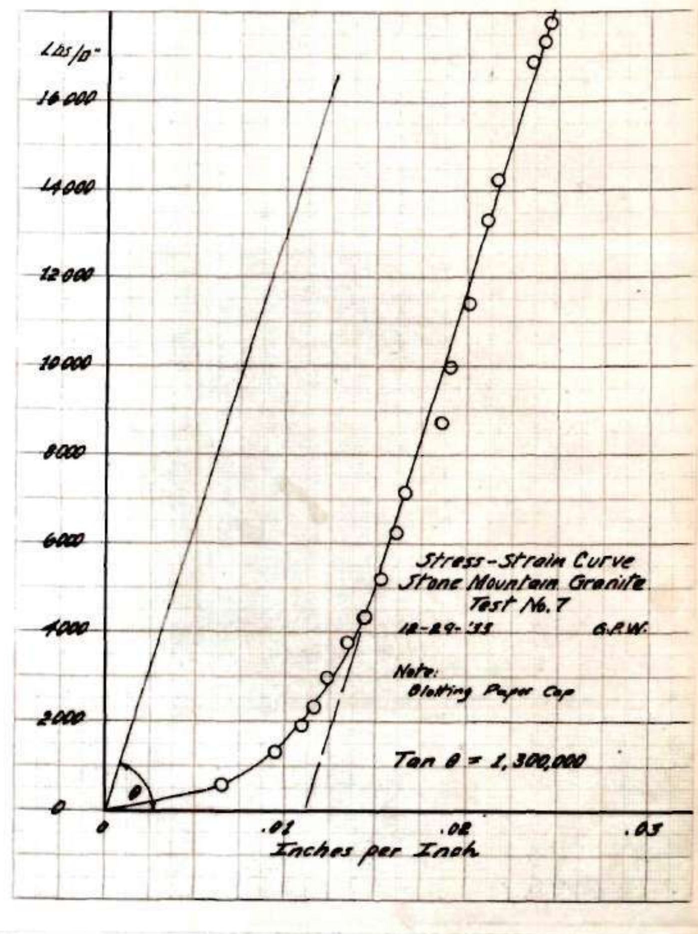
Date 12-29-33 Exp't No. 7
Kind of Material Stone Mt. Granite
Original Length 1.68" Final Length
Dia. inches Original 1.75" x 1.81" Final Area, Sq. inches Original Final
Modulus of Resilience Load per Sq. In. at Elastic Limit
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %
Yield Point, lb. per sq. in. Form of Section Elongation %

Reading No.	LOAD Actual	LOAD Per Sq. Inch	EXTENSOMETER READINGS Left	Right	Mean	Difference	ELONGATION Actual	ELONGATION Per Inch	Modulus of Elasticity
Units	Lbs.	#/□"	.378	.353	.3655		Ins.	"/"	
	0	0	.357	.351	.354	0	0		
	2000	632	.351	.348	.3495	.0015	.0115	.00685	
	4000	1262	.349	.346	.3475	.0045	.016	.0095	
	6000	1895	.347	.346	.3465	.002	.018	.0107	
	7000	2210	.346	.344	.345	.001	.019	.0113	
	9500	3000	.343	.343	.343	.0015	.0205	.0122	
	12000	3790	.341	.341	.341	.001	.0225	.0134	
	14000	4420	.340	.340	.340	.002	.0245	.0146	
	17000	5360	.338	.338	.338	.001	.0255	.0152	
	20000	6320	.337	.338	.3375	.002	.0275	.0164	
	23000	7260	.334	.335	.3345	.0005	.028	.0167	
	28000	8850	.333	.333	.333	.003	.031	.0185	
	31850	10080	.332	.331	.3315	.0015	.0325	.0194	
	36740	11580	.330	.329	.3295	.0015	.034	.0202	
	43000	13570	.329	.329	.329	.002	.036	.0214	
	46000	14520	—	—	—	.0005	.0365	.0217	
	53790	17000	.328	.324	.326	.003	.0395	.0235	
	57280	18000	.326	.322	.324	.002	.0415	.0247	
	60640	19150	.326	.319	.3225	.0015	.043	.0256	
	66550	21000							


Lbs/□"
12 000
10 000
8 000
6 000
4 000
2 000
0
Stress-Strain Curve
Stone Mountain Granite
Test No. 6
12-27-'33
G.R.W.
Note:
Plaster Paris & Cardboard Cap
θ
0
.01
.02
.03
.04
.05
.06
Inches per Inch
Tan θ = 293,000


Lbs/□"
12 000
10 000
8000
6 000
4000
2 000
0
Stress-Strain Curve
Stone Mountain Granite
Test No. 5
12-26-'33
G.R.W.
Note:
Plaster Paris & Cardboard Bed
θ
0
.001
.002
.003
.004
.005
Inches per Inch
Tan θ = 690,000


Lbs/□"
28 000
24 000
20 000
16 000
12 000
8 000
4 000
2 000
0
Stone Mountain Granite
Stress - Strain Curve
Test No. 8
1-9-'34
G.R.W.
Note:
Blotting Paper Bed
Tan θ = 2,300,000
0
.01
.02
.03
Inches per Inch


Lbs/□"
16 000
14 000
12 000
10 000
8000
6000
4000
2000
0
Stress-Strain Curve
Stone Mountain Granite
Test No. 7
12-29-'33
G.R.W.
Note:
Blotting Paper Cap
Tan θ = 1,300,000
θ
0
.01
.02
.03
Inches per Inch

Serial No. 58
DEPARTMENT OF EXPERIMENTAL ENGINEERING
GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST- *Compression* — TESTED BY

Date *1-9-34* Exp't No. *2*
Kind of Material *Creole Marble*
Original Length *1.98"* Final Length
Dia. inches {Original *1.98 x 2"* / Final} Area, Sq. inches {Original / Final}
Modulus of Resilience Load per Sq. In. at Elastic Limit
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %
Yield Point, lb. per sq. in. Form of Section Elongation %

Hydraulic Machine
Blotting Paper cap
Geo. P. Woollard

Reading No.	LOAD Actual	LOAD Per Sq. Inch	EXTENSOMETER READINGS Left	Right	Mean	Difference	ELONGATION Actual	Per Inch	Modulus of Elasticity
Units	Lbs.	#/□"	Inches				Ins.	%	
		0	.255	.203	.229				
	4000	1009	.255	.202	.2285	.0005	.0005	.000252	
	8000	2020	.257	.180	.2185	.0100	.0105	.0053	
	12000	3025	.252	.173	.2125	.006	.0165	.0083	
	16000	4040	.250	.170	.210	.0025	.0190	.0096	
	20000	5060	.248	.167	.2075	.0025	.0215	.01085	
	24000	6050	.247	.165	.206	.0015	.0230	.0116	
	28000	7060	.247	.163	.205	.001	.0240	.0121	
	32000	8070	.246	.161	.2035	.0015	.0255	.0129	
	36000	9080	.246	.159	.2025	.001	.0265	.0134	
	38000	9590	.245	.158	.2015	.001	.0275	.0139	
	40000	10090	.245	.156	.2005	.001	.0285	.0144	
	44000	11090	.244	.155	.1985	.002	.0305	.0153	
	48000	12100							
	Lateral Expansion								
		1.99	2.00						
		2.01	2.02						

Serial No. 58
DEPARTMENT OF EXPERIMENTAL ENGINEERING
GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST *Compression* — TESTED BY

Date *Dec. 26, 1933* Exp't No. *1*
Kind of Material *Creole Marble*
Original Length *1.97"* Final Length
Dia. inches {Original *1.98 x 2"* / Final} Area, Sq. inches {Original / Final}
Modulus of Resilience Load per Sq. In. at Elastic Limit
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %
Yield Point, lb. per sq. in. Form of Section Elongation %

Hydraulic Mach.
Paper capping
Geo. P. Woollard

Reading No.	LOAD Actual	LOAD Per Sq. Inch	[redacted] Left	Right	Mean	Difference	ELONGATION Actual	Per Inch	Modulus of Elasticity
Units	Lbs.		Lateral Expansion		Defl.				
	0		1.97"	2.00"	.303				
	8000	2020			.376	.007	.007	.00353	
	12000	3030			.361	.015	.022	.0111	
	16000	4040	1.97	2.00	.350	.011	.033	.0167	
	20000	5050			.338	.012	.045	.0227	
	24000	6060			.328	.010	.055	.0278	
	26000	6670			.324	.004	.059	.0298	
	28000	7070			.316	.008	.067	.0338	
	29600	7480	2.05	2.07					
				Revised Corrected Data					
				Load		Defl.	%		
				2020		.0035	.00177		
				3030		.0111	.0056		
				4040		.0258	.013		
				5050		.0388	.0196		
				6060		.0488	.0246		
				7070		.0598	.0353		

Serial No. 58
DEPARTMENT OF EXPERIMENTAL ENGINEERING
GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST- *Compression* — TESTED BY

Date *1-9-34* Exp't No.
Kind of Material *Etowah Marble*
Original Length *1.96"* Final Length
Dia. inches {Original *1.97 x 2"* / Final} Area, Sq. inches {Original / Final}
Modulus of Resilience Load per Sq. In. at Elastic Limit
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %
Yield Point, lb. per sq. in. Form of Section Elongation %

Hydraulic Machine
Blotting Paper cap
Geo. P. Woollard

Reading No.	LOAD Actual	LOAD Per Sq. Inch	EXTENSOMETER READINGS Left	Right	Mean	Difference	ELONGATION Actual	Per Inch	Modulus of Elasticity
Units	Lbs.	#/□"	Inches			Ins.	%		
	0	0	.224	.170	.197				
	4000	1015	.223	.164	.1935	.0035	.0035	.00179	
	8000	2030	.2195	.149	.184	.0095	.013	.00664	
	12000	3040	.217	.146	.1815	.0025	.0155	.00791	
	16000	4060	.213	.140	.1765	.005	.0205	.01045	
	20000	5070	.213	.138	.1755	.001	.0215	.011	
	24000	6090	.210	.135	.1725	.003	.0245	.0125	
	28000	7110	.210	.133	.1715	.001	.0255	.01302	
	32000	8120	.210	.130	.170	.001	.0265	.0135	
	36000	9140	.207	.127	.167	.003	.0295	.01505	
	40000	10150							
	Lateral Expansion								
		2.00	1.99						
		2.01	2.00						

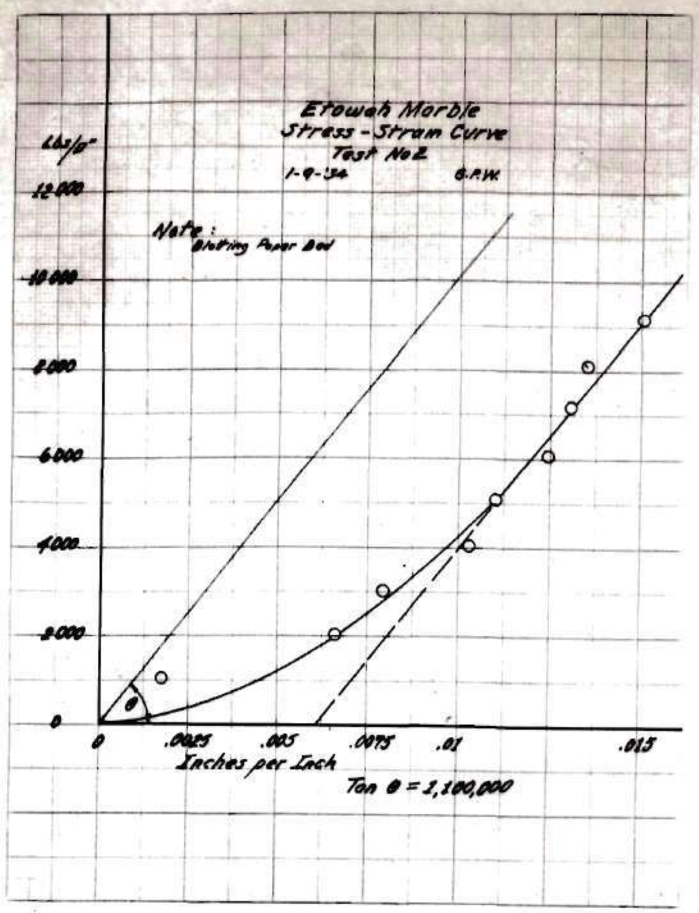
Serial No. 58
DEPARTMENT OF EXPERIMENTAL ENGINEERING
GEORGIA SCHOOL OF TECHNOLOGY

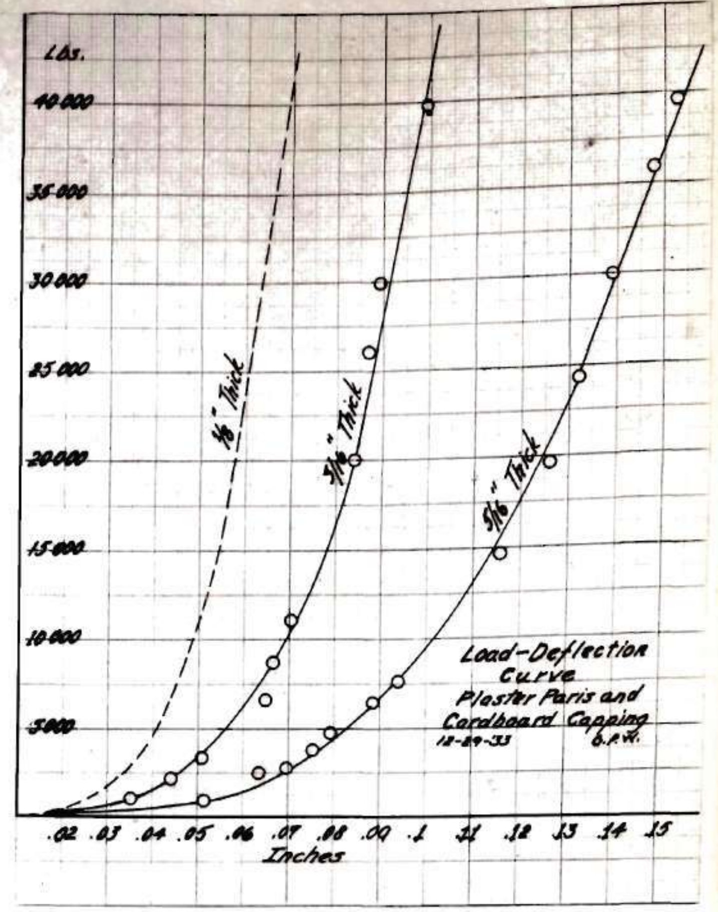
[redacted] TEST- *Compression* — TESTED BY

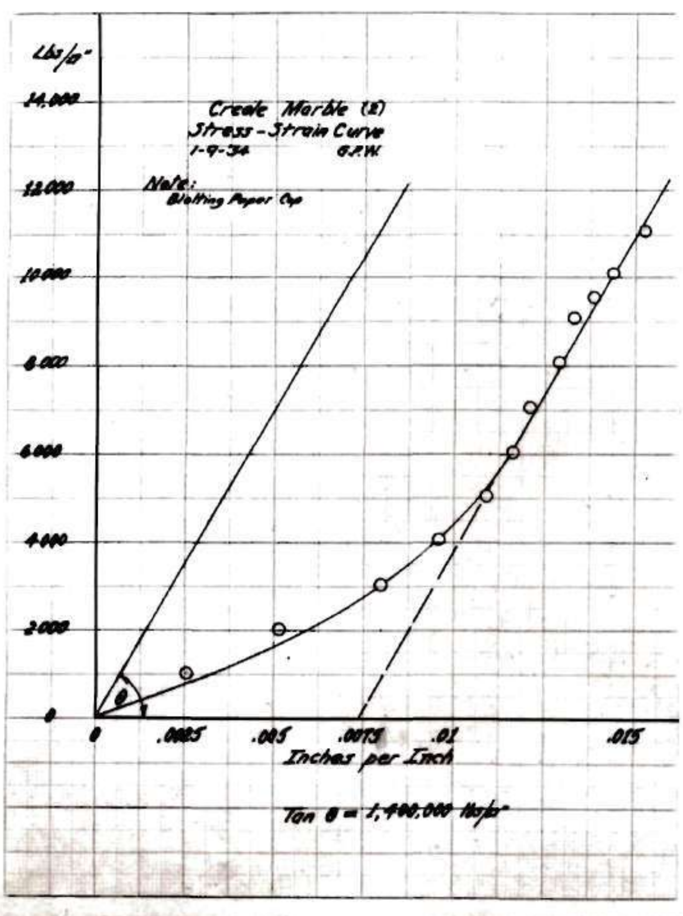
Date *12-29-'33* Exp't No.
Kind of Material *Plaster Paris & Card Board*
Original Length *5/16"* Final Length
Dia. inches {Original *1.75 x 1.8"* / Final} Area, Sq. inches {Original / Final}
Modulus of Resilience Load per Sq. In. at Elastic Limit
Maximum Load lb. per sq. in. Breaking Load lb. per sq. in. Reduction in Area %
Yield Point, lb. per sq. in. Form of Section Elongation %

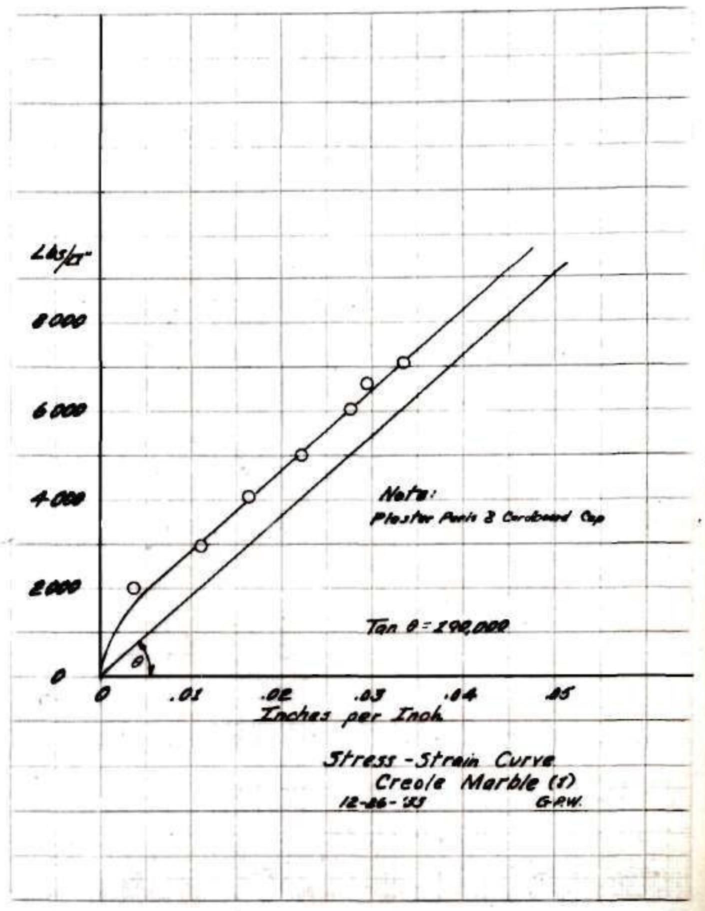
Riehle Machine
Plaster Paris cap and cardboard
Geo. P. Woollard

Reading No.	LOAD Actual	LOAD Per Sq. Inch	EXTENSOMETER READINGS Left	Right	Mean	Difference	ELONGATION Actual	Per Inch	Modulus of Elasticity
Units	0		.408	.363	.3855				
	1000		.341	.328	.3345	.051	.051		
	2600		.330	.314	.322	.0125	.0635		
	3000		.326	.309	.3175	.0055	.0690		
	4000		.320	.302	.311	.0065	.0755		
	5000		.314	.302	.308	.003	.0785		
I	6610		.308	.287	.2975	.0105	.089		
	8000		.302	.283	.2925	.005	.094		
	15000		.380	.262	.271	.0215	.1155		
	20000		.269	.252	.2605	.0105	.126		
	25000		.264	.245	.2545	.006	.132		
	30000		.255	.238	.2465	.008	.140		
	36000		.243	.231	.237	.0095	.1495		
	40000		.237	.228	.2325	.0045	.154		
Using a 3/16" Section									
	0		.283	.236	.2595				
	1000		.233	.215	.224	.0355	.0355		
	2000		.229	.205	.217	.007	.0425		
	3000		.224	.198	.211	.006	.0485		
	6380		.213	.180	.1965	.0145	.063		
	8500		.210	.179	.1945	.002	.065		
	11000		.207	.174	.1905	.004	.069		
	20000		.198	.159	.1765	.014	.083		
	26160		.194	.153	.1765	.003	.086		
	30620		.191	.150	.1705	.003	.089		
	40000		.187	.133	.160	.0105	.0995		


Etowah Marble
Stress - Strain Curve
Test No 2
1-9-'34 G.P.W.
Lbs/□"
Note:
Blotting Paper Bed
12,000
10,000
8000
6000
4000
2000
0
.0025
.005
.0075
.01
.015
Inches per Inch
Tan θ = 1,100,000


Lbs.
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5000
1/8" Thick
3/16" Thick
5/16" Thick
Load-Deflection
Curve
Plaster Paris and
Cardboard Capping
12-29-'33 G.P.W.
.02 .03 .04 .05 .06 .07 .08 .09 .1 .11 .12 .13 .14 .15
Inches


Lbs/□"
14,000
Creole Marble (2)
Stress - Strain Curve
1-9-'34 G.P.W.
Note:
Blotting Paper Cap
12,000
10,000
8000
6000
4000
2000
0
.0025
.005
.0075
.01
.015
Inches per Inch
Tan θ = 1,400,000 lbs/□"


Lbs/□"
8000
6000
4000
2000
0
Note:
Plaster Paris & Cardboard Cap
Tan θ = 290,000
.01
.02
.03
.04
.05
Inches per Inch
Stress - Strain Curve
Creole Marble (1)
12-26-'33 G.P.W.

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST- Compression — TESTED BY

Date 12-26-33 Exp't No.

Kind of Material Serpentine

Original Length 1.30" Final Length

Dia. inches { Original 1.29"x1.30" Final } Area, Sq. inches { Original Final }

Modulus of Resilience Load per Sq. In. at Elastic Limit

Maximum Load lb. per sq. in. Breaking Load lb. per sq. in.

Yield Point, lb. per sq. in. Form of Section

Riehle Machine

Plaster Paris cap on cardboard

Geo. P. Woollard

Reduction in Area %

Elongation %

Reading No.	Load: Actual	Load: Per Sq. Inch	Extensometer Readings: Left	Right	Mean	Difference	Elongation: Actual	Per Inch	Modulus of Elasticity
Units	Lbs.	lbs/□"	inches				Inches	"/"	
	0	0	1.85	.2.09	1.97				
	500	298	1.85	2.09	1.97	–			
	1000	596	1.82	2.05	1.935	.035	.035	.0269	22,200
	2000	1192	1.82	2.05	1.935	–	.035	.0269	——
	3000	1790	1.82	2.04	1.93	.005	.04	.0308	58,000
	4000	2385	1.80	2.02	1.91	.02	.06	.0461	51,700
	4500	2683	1.80	2.01	1.905	.005	.065	.0500	53,600
	5000	2980	1.79	2.00	1.895	.01	.075	.0576	51,700
	5500	3280	1.79	1.99	1.89	.005	.08	.0615	53,400
	6000	3680	1.80	1.97	1.885	.005	.085	.0654	56,400
	6400	3820							
				Data for Corrected Curve					
	Lateral Expansion			Load/□"	Elongation Actual	"/"	Corr.		
Load	Inches			576	.001	.00077	-.034		
1000	1.26	1.31		2385	.004	.00307	-.054		
2000	1.28	1.31		2980	.019	.0146	-.056		
6000	1.28	1.33		3680	.025	.0192	-.060		

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST Compression — TESTED BY

Date Jan. 24, 1934 Exp't No.

Kind of Material Elberton Blue Granite

Original Length 2.0" Final Length

Dia. inches { Original 2.05"x2.05" Final } Area, Sq. inches { Original Final }

Modulus of Resilience Load per Sq. In. at Elastic Limit

Maximum Load lb. per sq. in. Breaking Load lb. per sq. in.

Yield Point, lb. per sq. in. Form of Section

Note: Blotter Bed

Geo. P. Woollard

Reduction in Area %

Elongation %

Reading No.	Load: Actual	Load: Per Sq. Inch	Extensometer Readings: Left	Right	Mean	Difference	Elongation: Actual	Per Inch	Modulus of Elasticity
Units	0 Tons	0	.456	.436	.447				
	5	2380	.456	.433	.4445	.0035	.0035	.00175	
	7	3332	.448	.430	.439	.0055	.009	.0045	
	8	3808	.446	.430	.438	.001	.010	.005	
	10	4760	.442	.428	.435	.003	.013	.0065	
	12	5712	.439	.429	.4335	.0015	.0145	.00775	
	14	6664	.435	.428	.4315	.002	.0165	.00825	
	16	7616	.432	.428	.430	.0015	.018	.009	
	18	8568	.429	.426	.4275	.0025	.0205	.01025	
	20	9520	.427	.426	.4265	.001	.0215	.01075	
	22	10472	.424	.426	.4255	.001	.0225	.01125	
	24	11424	.426	.424	.425	.0005	.023	.0115	
	28	13328	.420	.424	.422	.003	.026	.013	
	30	14280	.418	.423	.42205	.0015	.0275	.01375	
	32	15232	.417	.422	.4195	.001	.0285	.01425	
	34	16184	.416	.422	.419	.0005	.029	.0145	
	36	17136	.415	.422	.4185	.0005	.0295	.01475	
	38	18088	.414	.4215	.418	.0005	.030	.015	
	40	19040	.413	.421	.417	.001	.031	.0155	
	42	19992	.412	.417	.4145	.0025	.0335	.01675	
	44	20944	.411	.416	.4135	.001	.0345	.01725	
	46	21896	.410	.416	.413	.0005	.035	.0175	
	48	22848	.409	.416	.4125	.0005	.0355	.01775	
	50	23800	.4085	.415	.410	.0010	.037	.0185	
	54	25,704	Failure						

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST Compression — TESTED BY

Date Feb. 24, 1934 Exp't No.

Kind of Material Georgia White Marble

Original Length 1.98" Final Length

Dia. inches { Original 1.99"x2.00" Final } Area, Sq. inches { Original Final }

Modulus of Resilience Load per Sq. In. at Elastic Limit

Maximum Load lb. per sq. in. Breaking Load lb. per sq. in.

Yield Point, lb. per sq. in. Form of Section

Note: Blotter Bed

Geo. P. Woollard

Reduction in Area %

Elongation %

Reading No.	Load: Actual	Load: Per Sq. Inch	Extensometer Readings: Left	Right	Mean	Difference	Elongation: Actual	Per Inch	Modulus of Elasticity
Units	0	0	.424	.371	.3975	0	0		
	4 Ton	2000	.359	.423	.3905	.007	.007	.0035	
	6	3000	.351	.421	.386	.0045	.0115	.00575	
	8	4000	.350	.418	.384	.002	.0135	.00675	
	10	5000	.347	.417	.382	.002	.0155	.00775	
	12	6000	.344	.416	.380	.002	.0175	.00875	
	15	7500	.339	.415	.377	.003	.0205	.01025	
	16	8000	.338	.414	.376	.001	.0215	.01075	
	18	9000	.335	.411	.373	.003	.0245	.01225	
	20	10000	.331	.409	.370	.003	.0275	.01375	
	21	10500	Failure						

Serial No. 58

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

[redacted] TEST - Compression — TESTED BY

Date Feb. 24, 1934 Exp't No.

Kind of Material Elberton Pink Granite

Original Length 2.03" Final Length

Dia. inches { Original 1.95"x2.05" Final } Area, Sq. inches { Original Final }

Modulus of Resilience Load per Sq. In. at Elastic Limit

Maximum Load lb. per sq. in. Breaking Load lb. per sq. in.

Yield Point, lb. per sq. in. Form of Section

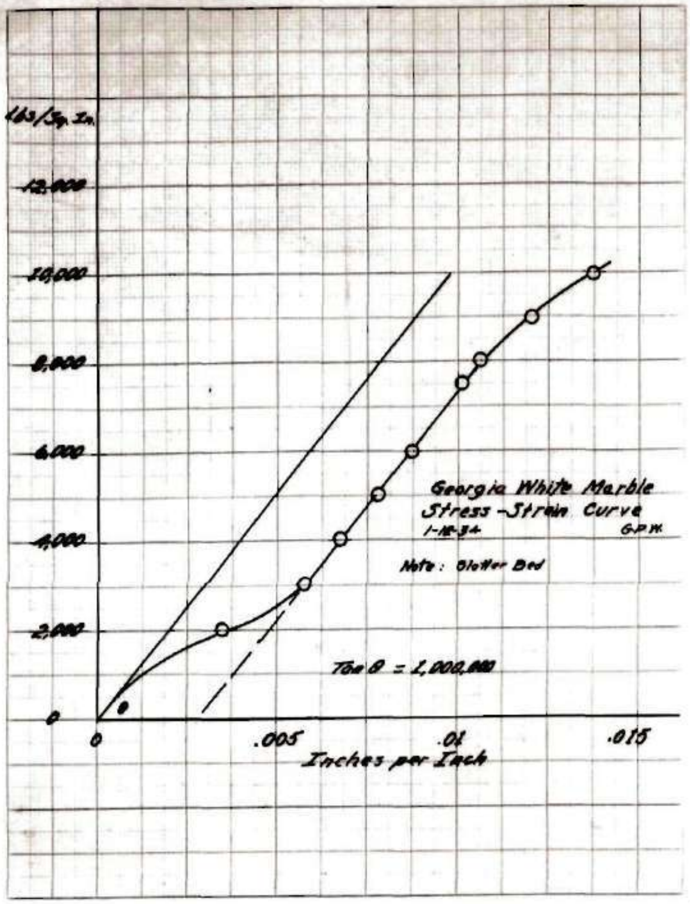
Note: Blotter Bed.

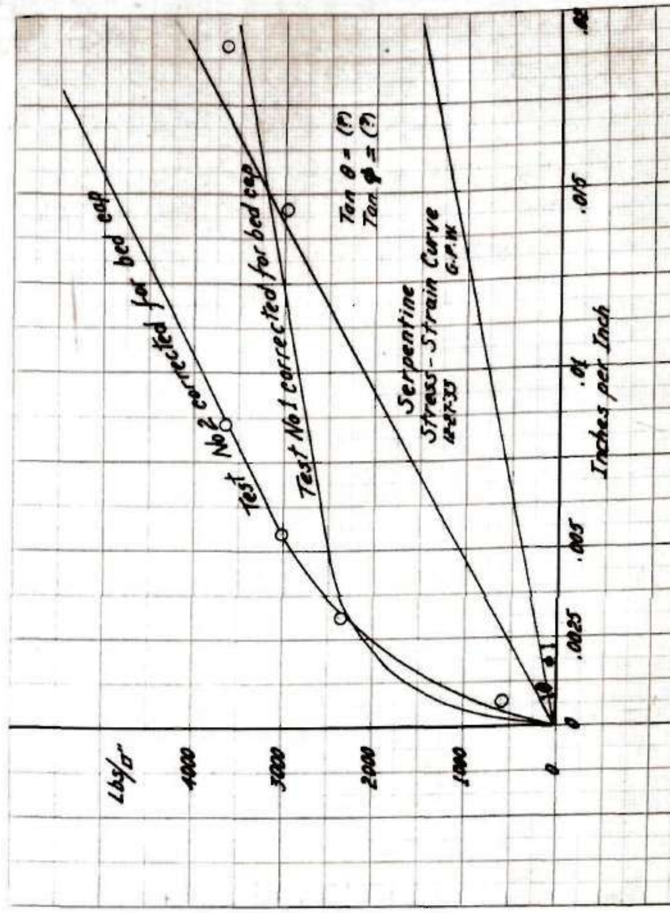
Geo. P. Woollard

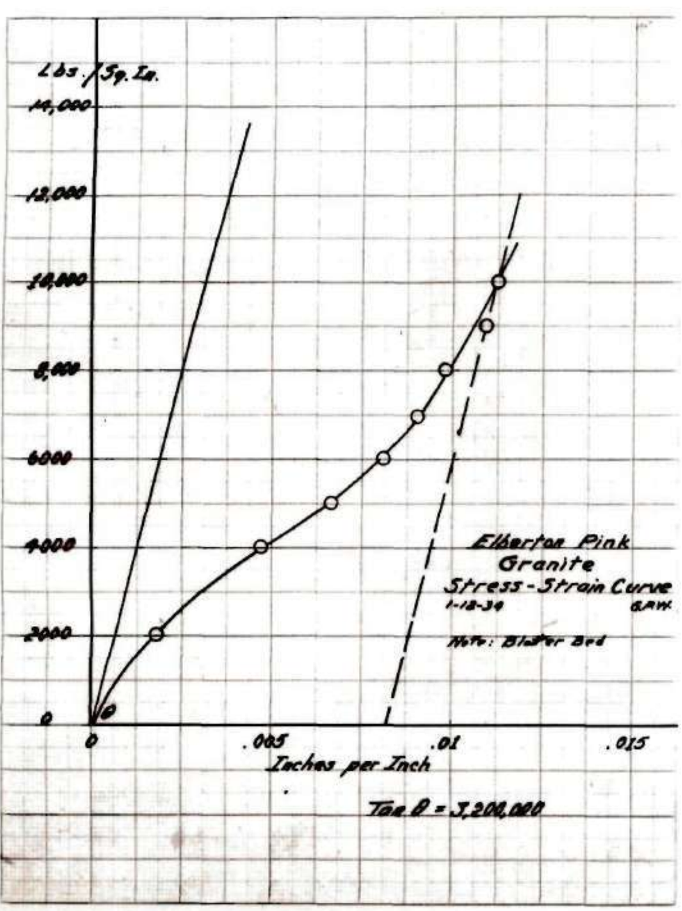
Reduction in Area %

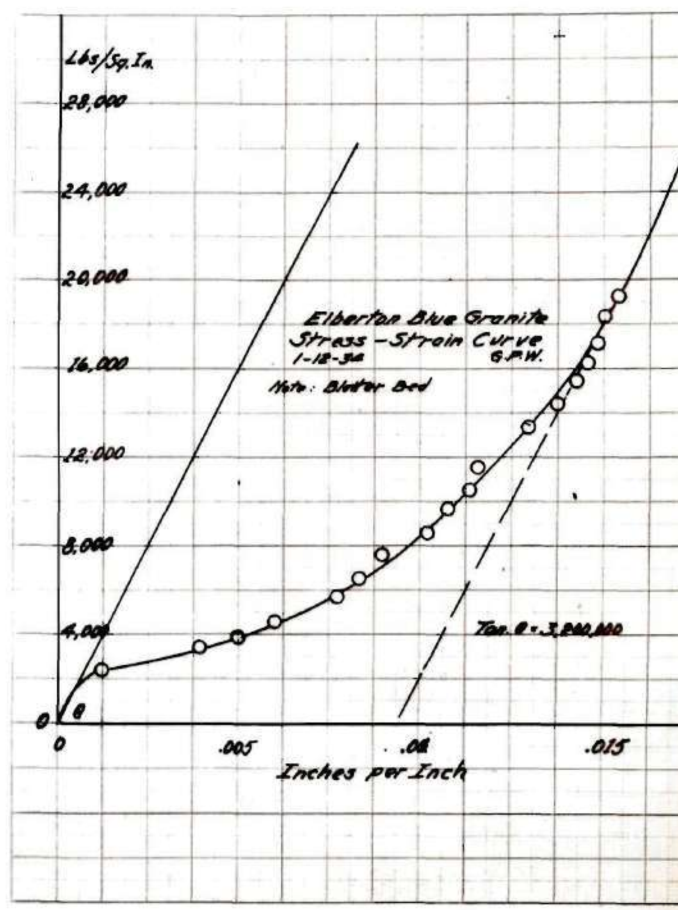
Elongation %

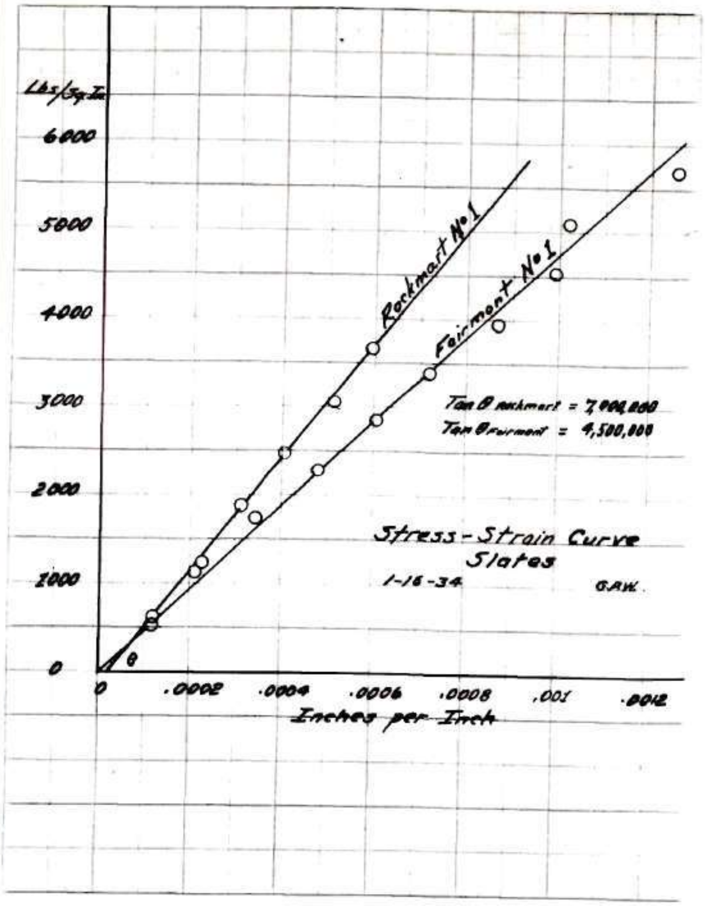
Reading No.	Load: Actual	Load: Per Sq. Inch	Extensometer Readings: Left	Right	Mean	Difference	Elongation: Actual	Per Inch	Modulus of Elasticity
Units	4 Tons	2000	.354	.373	.3635	.0035	.0035	.0017	
	8	4000	.340	.373	.3575	.006	.0095	.0047	
	10	5,000	.336	.372	.354	.0035	.0130	.0065	
	12	6,000	.332	.371	.3515	.0035	.0165	.0082	
	14	7000	.330	.370	.350	.0015	.018	.009	
	16	8,000	.328	.369	.3485	.0015	.0195	.0097	
	18	9000	.325	.367	.346	.0025	.022	.011	
	20	10,000	.326	.365	.3455	.0005	.0225	.0112	
	24	12,000	.322	.342	.332	.0135			
	26	13,000	.317	.320	.3185	.0135			
	27	13,600	Failure						

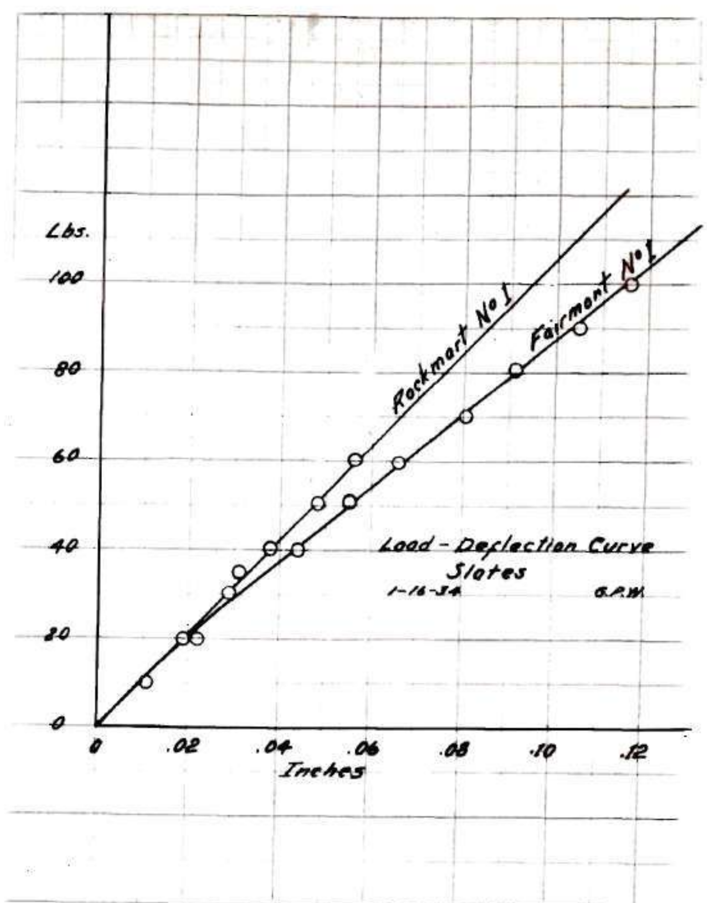

Lbs/Sq. In.
12,000
10,000
8,000
6,000
4,000
2,000
0
0
.005
.01
.015
Inches per Inch
Georgia White Marble
Stress-Strain Curve
1-12-34
G.P.W.
Note: Blotter Bed
Tan θ = 1,000,000


Test No 2 corrected for bed cap
Test No 1 corrected for bed cap
Tan θ = (?)
Tan φ = (?)
Serpentine
Stress-Strain Curve
12-27-33
G.P.W.
Inches per Inch
.02
.015
.01
.005
.0025
0
Lbs/□"
4000
3000
2000
1000
0


Lbs./Sq. In.
14,000
12,000
10,000
8,000
6000
4000
2000
0
0
.005
.01
.015
Inches per Inch
Elberton Pink
Granite
Stress-Strain Curve
1-12-34
G.P.W.
Note: Blotter Bed
Tan θ = 3,200,000


Lbs/Sq. In.
28,000
24,000
20,000
16,000
12,000
8,000
4,000
0
0
.005
.01
.015
Inches per Inch
Elberton Blue Granite
Stress-Strain Curve
1-12-34
G.P.W.
Note: Blotter Bed
Tan θ = 3,200,000





Serial No. 50

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

TRANSVERSE TEST — TESTED BY

Date 1-16-'34 Exp't No. 1

Kind of Material Gray Slate

Material from Columbia Slate Co. Rockmart

Dimensions .255" x 4.5" x 16"

Distance Between Knife Edges 12"

Manner of Loading Mid-point

Geo. J. Woollard

Reading No.	Load in Lbs.	Stress in Outer Fiber #/□" Tensile	Compressive	Deflection: Reading in Inches	Deflection: Total in Inches	Unit Deformation in Outer Fiber Inches/Inch	Modulus of Elasticity
1 No. 1	0	0	.018				
2	10	615	.028	.010	.010	.0001064	5,777,000
3	20	1230	.039	.011	.021	.000228	5,390,000
4	30	1845	.047	.008	.029	.000305	6,050,000
5	40	2460	.056	.009	.038	.000405	6,060,000
6	50	3076	.066	.010	.048	.000512	6,010,000
7	60	3690	.074	.008	.056	.000596	6,190,000
8	70	4305					
9	80	4920					
10							
11							
12 No. 2	thickness = .245"						
13	0	0	.008				
14	10	660	.017	.009	.009	.000092	7,170,000
15	20	1320	.028	.011	.020	.000204	6,460,000
16	30	1980	.039	.011	.031	.000317	6,250,000
17	40	2640	.051	.012	.043	.00044	6,000,000
18	50	3300	.064	.013	.056	.000572	5,770,000
19	60	3960	.076	.012	.068	.000695	5,720,000
20	70	4620					
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							
32							

Serial No. 50

DEPARTMENT OF EXPERIMENTAL ENGINEERING

GEORGIA SCHOOL OF TECHNOLOGY

TRANSVERSE TEST — TESTED BY

Date 1-16-'34 Exp't No. 2

Kind of Material Green Slate

Material from Fairmont

Dimensions .262" x 4.6" x 16.1"

Distance Between Knife Edges 12"

Manner of Loading Mid-point

Reading No.	Load in Lbs.	Stress in Outer Fiber #/□" Tensile	~~Compressive~~ Δy	Deflection: Reading in Inches	Deflection: Total in Inches	Unit Deformation in Outer Fiber Inches/Inch	Modulus of Elasticity
1 No. 1	0	0	.033	0	0		
2	10	570	.047	.011	.011	.00012	4,750,000
3	20	1140	.052	.008	.019	.000208	5,490,000
4	30	1710	.065	.013	.032	.000349	4,900,000
5	40	2280	.077	.012	.044	.000481	4,740,000
6	50	2850	.088	.011	.055	.000601	4,740,000
7	60	3420	.099	.011	.066	.000721	4,740,000
8	70	3990	.113	.014	.080	.000874	4,570,000
9	80	4560	.124	.011	.091	.000994	4,590,000
10	90	5130	.138	.014	.105	.00109	4,710,000
11	100	5700	.141	.011	.116	.00127	4,490,000
12	108	6160					
13							
14							
15 No. 2	Thickness .163						
16	0		.021				
17	10	1128	.038	.017	.017	.000132	8,540,000
18	20	2246	.054	.016	.033	.000256	8,780,000
19	30	3384	.068	.014	.047	.000365	9,270,000
20	40	4512	.088	.020	.067	.000521	8,660,000
21	50	5640	.106	.018	.085	.00066	8,400,000
22	60	6768	.122	.016	.101	.000785	8,610,000
23	68	7650					
24							
25							
26							
27							
28							
29							
30							
31							
32							

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MODULUS OF ELASTICITY

Free Height Ins.	Bearing Surface Ins.	Cap Material	Load Pounds	Defor. Ins.	Modulus Lbs/Sq.In.
		STONE MOUNTAIN GRANITE			
2.05	1.62x1.80	Cardboard	35,600	.131	280,000
2.01	1.70x1.80	"	27,800	.085	290,000
1.70	1.86x2.04	P.P. and C.	25,000	.106	260,000
1.63	1.7x1.78	P.P. and C.	32,000	.190	410,000
1.74	1.80x2.00	P.P. and C.	36,000	.066	690,000
1.74	1.73x1.77	P.P. and C.	30,000	.096	293,000
1.68	1.75x1.81	Blotting P.	60,640	.043	1,300,000
1.68	1.86x1.94	" "	88,000	.043	2,3000000
		CREOLE MARBLE (Bush Hammered)			
1.98	1.98x2.00	Blotting C.	44,000	.0305	1,400,000
1.97	1.98x2.00	P.P. and C.	26,000	.059	224,000
		ETOWAH MARBLE (Bush Hammered)			
1.96	1.97x2.00	Blotting P.	36,000	.029	1,100,000
		GEORGIA WHITE MARBLE (Bush Hammered)			
1.98	1.99x2.00	Blotting P.	32,000	.0215	1,000,000
		ELBERTON BLUE GRANITE			
2.00	2.05x2.05	Blotting P.	76,000	.030	3,200,000
		ELBERTON PINK GRANITE			
2.03	1.95x2.05	Blotting P.	40,000	.022	3,200,000
		SERPENTINE (VERDE ANTIQUE)			
1.30	1.29x1.30	P.P. and C.	6,000	.085	54,600
1.29	1.27x1.30	P.P. and C.	6,000	.051	140,000

Load	Section	Span	Deflection	Modulus
		GREY ROCKMART SLATE		
80	0.255x4.50	12	.056	6,100,000 (Ave. 2 tests)
		GREEN FAIRMONT SLATE		
108	0.262x4.60	12	.116	4,750,000
68	0.186x4.60	12	.101	8,600,000

DISCUSSION OF RESULTS

In conducting this work it is not advisable to use plaster of paris capping on specimen, or to introduce thick sheets of cardboard between the specimen and the bearing plates of the machine as most of the deformation that will be observed will be due to the crushing of these capping materials. To obtain a check upon this, thin layers of plaster of paris sandwiched between thin sheets of cardboard, such as were used on the compression tests of many of the samples, were loaded within the same limits as met with in crushing the specimen and the deformation measured over the entire loading range. The results show that practically 60% of the observed deformation encountered with capped specimen could be attributed to the capping material where the specimen were capped and crushed the same day. The author obtained the best results using thin sheets of blotting paper as capping material and measuring the deformation with in-side micrometers between the upper and lower head of the machine at two points diametrically opposite so as to eliminate any chance for error.

In testing for the Modulus of Elasticity under transverse loading a standard deflectometer reading to $\frac{1}{1000}$ of an inch was used directly under the point of load application. This value was only calculated for slates on account of the difficulty met with in obtaining specimen for this test.

Since the author completed his work investigating the Modulus of Elasticity, there has come to his attention the work of D. W. Kessler, Research Associate, and W. H. Sligh, Associate Physicist of the Bureau of Standards of the Department of Commerce. They ran extensive tests on the various Limestones of the United States. In determining the Modulus of Elasticity their method was the same as that originally had by the author when the various tests were first outlined, namely, the using of a specimen of sufficient size to allow the installation of a Berry Strain Gage over an increment of length. As the author found it impossible to obtain such specimen, he had to endeavor to devise some other method for determining this quality. The method used has been previously outlined. It was hoped that by determining the deformation in the capping material to be able to make such corrections as to give comprehensive results. However, on account of the difficulty met with in limiting the amount of capping material no definite correction could be used and hence the results have no value. Where only blotting paper was used the author drew a corrected curve through the zero ordinate parallel to that portion of the curve that had a definite slope. This was a decided departure as all previous work had determined the Modulus of Elasticity as being the slope of the tangent to the curve at the ordinate. However, as all experimental work failed to offer any logical support to this method, the author was guided by his findings rather than precedent. The shape of stress-strain curves as determined were very similar to what other investigators found on stone. All show a changing rate of slope up to around 5,000 pounds per square inch. The author believes that this is due to two causes; some slight internal adjustment, and the adjustment of the bearing surfaces to the heads which is responsible for the greater part. In support of this contention is offered the Load-Deflection curves for the capping material alone which gave the same shape as when the stones themselves were tested, and the fact that when bush-hammered specimen were tested using only blotting paper the period of adjustment was of longer duration; that is, until the crushed surfaces were compacted. In both cases as soon as this preliminary adjustment was over the slope of the curve became constant. Therefore, it seems logical that the Modulus of Elasticity would be the slope of that portion of the curve where it is constant. If this is true, then a corrected curve parallel to that portion of the original where the slope is constant can be drawn. The author is substantiated in these conclusions by Kessler and Sligh[1] who say,"In general it will be noted that the curves are straight lines except at low loads. Usually in determining the Modulus of Elasticity this variation is

1. Physical Properties of the Principal Commercial Limestones of the United States, Kessler and Sligh; p. 511

attributed to the uncertainity of taking measurements at these low loads, but there is considerable evidence to indicate that these variations are due to some pecularity in the structure of the material which influences its behavior under stress. The modulus values were computed from the slope of the straight line." They give the following table as computed from available data:

Slate	9,000,000 - 15,000,000
Marble	7,200,000 - 14,500,000
Serpentine . .	4,800,000 - 9,600,000
Granite	5,700,000 - 8,200,000
Sandstone . . .	1,900,000 - 7,700,000
Limestone . . .	1,500,000 - 12,400,000

Those tests as conducted using a thin sheet of blotting paper, therefore, might be admitted using the modulus as the slope of the straight line. For Stone Mountain Granite this was found to range from 1,300,000 to 2,300,000 pounds per square inch. On the bush-hammered marble specimen it ranged from 1,100,000 to 1,400,000 pounds per square inch. This seems at great variance from the previous table, but is partially supported by the work of Buckley and the fact that on the marble specimen the severe treatment received gave a dead surface on both bearing surfaces that gave an excessive deformation. Parks[1] quotes Buckley on the Granites of Wisconsin as follows, "21 granites and rhyolites gave an average modulus of Elasticity of 1,111,000 pounds per square inch. They ranged from 156,000 to 2,070,000."

1. Building and Ornamental Stones of Canada, Parks; p. 47

Print A SUMMARY OF RESULTS ON CRUSHING STRENGTH

Surface Bearing Ins.	Load Ultimate Lbs.	Stress Compressive Lbs./Sq.In.	Authority	Date	Remarks
		STONE MOUNTAIN GRANITE			
2.05x2.00	No failure at 85,000 Lbs. -		Washington Navy Yd.	1887	Probablly on bed
1.99x1.99	50,325	12,710	" " "	"	)
1.99x1.99	48,760	12,320	" " "	"	) Probablly on grain
2.02x2.02	65,610	16,100	" " "	"	)
2.00x2.01	50,000	12,438	Purdue University	About 1890	
1.99x2.01	57,700	14,435	" "	" "	
2.04x2.04	53,700	12,904	" "	" "	All probablly on grain
2.04x2.07	55,700	13,190	" "	" "	
2.01x2.03	54,700	13,406	" "	" "	
2.02x2.05	53,700	12,726	" "	" "	
?		25,630	Watertown Arsenal	1894	On bed
?		28,130	" "	"	"
2" Cube	83,100	20,560	Watertown Arsenal	1924	On bed (?)
"	84,400	21,060	" "	"	"
"	87,800	21,950	" "	"	"
1.94x1.95	59,800	15,820	Author	1933	On Grain
1.90x1.94	58,000	15,730	"	"	"
1.88x2.04	56,600	14,780	"	"	"
1.85x1.87	82,000	22,500	"	"	On Bed
1.75x1.81	66,500	21,000	"	"	"
1.86x1.94	98,000	27,190	"	"	"
1.62x1.80	35,600	12,280	"	"	On Grain
1.70x1.80	27,800	9,080	"	"	"
1.86x2.04	48,900	12,980	"	"	"
1.70x1.78	35,000	11,560	"	"	"
1.80x2.00	43,400	12,020	"	"	"
1.73x1.77	32,760	10,680	"	"	"

Print A SUMMARY OF RESULTS ON CRUSHING STRENGTH

Bearing Surface Ins.	Ultimate Load Pounds	Compressive Stress Lbs/Sq.In.	Authority	Date	Remarks
		ELBERTON BLUE BIOTITE GRANITE			
3.07x3.06		26,340	Watertown Arsenal	1894	On bed
2.97x3.16		23,860	" "	"	"
2.00x2.11	82,000	19,460	Author	1933	On Grain
2.13x2.16	88,000	19,000	"	"	"
2.00x2.10	73,000	17,790	"	"	"
2.05x2.04	108,000	25,704	"	"	On bed
		ELBERTON GRAY BIOTITE GRANITE			
1.85x2.05	69,600	18,380	Author	1933	On Grain
2.00x2.08	71,200	17,140	"	"	"
1.90x2.05	66,400	17,060	"	"	"
		GEORGIA WHITE MARBLE			
0.99x1.00	11,300	11,414	University of Tennessee	1870	On bed
0.99x1.00	10,990	11,010	" "	"	"
0,98x1.00	10,800	11,020	" "	"	"
?		10,218-10,697	U.S.Bureau of Standards	1919	On bed dry
?		12,456-18,672	" "	"	" wet
?		17,577-21,521	" "	"	" frozen
1.98x2.00	35,200	8,880	Author	1933	Bush Hammered Specimen
1.90x2.00	29,400	7,590	"	"	
2.00x2.00	40,000	10,000	"	"	
		ITALIAN TRAVERTINE (Average of 5 tests)			
1.10x1.14		3,175-6,530	Author	1933	

Print A SUMMARY OF RESULTS ON CRUSHING STRENGTH

Bearing Surface Ins.	Ultimate Load Pounds	Compressive Stress Lbs/Dq. In.	Authority	Date	Remarks
	GEORGIA WHITE MARBLE (Continued)				
?		9,079-9,409	U.S.Bureau of Standards	1919	On bed dry
?		16,447-17,898	" "	"	On edge wet
?		8,547-9,057	" "	"	On edge frozen
		PINK ETOWAH MARBLE			
1.00x1.00	13,200	13,200	University of Tennessee	1870	On bed
0,99x0,99	12,000	12,344	" "	"	"
0.98x0.99	12,300	12,540	" "	"	"
6.01x6.03	384,400	10,642	Watertown Arsenal	1886	
?		10,919-12,171	U.S.Bureau of Standards	1919	On bed dry
?		9,414-11,095	" "	"	" wet
?		9,569-11,083	" "	"	" frOzen
?		9,755-10,643	" "	"	On edge dry
?		10,856	" "	"	" wet
?		7,383-9,919	" "	"	" frozen
1.92x2.00	32,000	8,290	Author	1933	Bush Hammered Specimen
1.95x1.96	34,000	8,890	"	"	
2.00x2.00	33,800	8,445	"	"	
1.97x2.00	40,000	10,150	"	"	
		GEORGIA TRAVERTINE (MARL)			
2.00x2.16	14,690	3,395	Author	1933	
2.05x2.08	7,490	1,850	"	"	Failed on fossi
2.01x2.10	11,850	2,840	"	"	
2.00x2.00	14,200	3,554	"	"	
1.35x1.36	9,170	4,990	"	"	
1.36x1.36	6,960	3,765	"	"	

Print A SUMMARY OF RESULTS ON CRUSHING STRENGTH

Bearing Surface Ins.	Ultimate Load Pounds	Comppessive Stress Lbs/Sq.In.	Authority	Date	Remarks
		CLOUDED CREOLE MARBLE			
1.00x1.00	13,900	13,900	University of Tennessee	1870	On bed
1000x1.00	13,100	13,100	" "	"	"
1.00x1.00	13,200	13,200	" "	"	"
5.99x6.00	434,100	12,078	Watertown Arsenal	1886	
?		11,050-12,217	U.S.Bureau of Standards	1919	On bed dry
?		8,719-10,233	" "	"	" wet
?		9,875-10,583	" "	"	" frozen
?		11,244-12,572	" "	"	On edge dry
?		8,350-8,677	" "	"	" wet
?		9,336-10,042	" "	"	" frozen
2.00x2.00	36,200	9,050	Author	1933	Bush Hammered Specimen
1.99x2.00	40,000	10,060	"	"	
1.97x1.99	46,400	11,790	"	"	
1.98x2100	48,000	12,100	"	"	
1.98x2.00	29,600	7,480	"	"	
		VERDE ANTIQUE (SERPENTINE)			
1.30x1.30	4,870	2,882	Author	1933	
1.30x1.32	4,070	2,375	"	"	
1.30x1.30	9,310	5,510	"	"	
1.30x1.31	3,480	2,042	"	"	
1.26x1.31	8,210	4,770	"	"	
1.29x1.30	6,400	3,820	"	"	
1.27x1.30	6,800	4,120	"	"	

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A SUMMARY OF RESULTS ON TRANSVERSE STRENGTH

Load Lbs.	Loading Position	Section Ins.	Span Ins.	Tensile Stress Lbs/Sq.In.	Authority	Date
			STONE MOUNTAIN GRANITE			
246	Flat	0.92x 1.90	6	1,365	Author	1933
480	"	0.90x1.80	3	1,485	"	"
520	"	0.85x1.92	3	1,685	"	"
855	Edge	1.05x1.86	3	2,120	"	"
			ELBERTON PINK GRANITE			
436	Flat	0.72x2.40	5	2,622	Author	1933
			ELBERTON GREY GRANITE			
492	Flat	0.75x2.15	4	2,443	Author	1933
762	"	1.00x2.10	4	2,480	"	"
500	"	0.85x1.90	5	2,738	"	"
926	Edge	1.10x1.35	4	2,775	"	"
			ELBERTON BLUE BIOTITE GRANITE			
1,130	Flat	1.05x2.25	5	3,418	Author	1933
660	"	0.96x2.25	5	2,382	"	"
			VERDE ANTIQUE (Coarse veining)			
380	Flat	1.64x1.30	4	823	Author	1933
406	"	1.85x1.27	5	1,022	"	"
230	"	2.06x1.30	5	496	"	"
844	"	1.96x1.15	5	2,432	"	"

A SUMMARY OF RESULTS ON TRANSVERSE STRENGTH

Load Lbs.	Loading Position	Section Ins.	Span Ins.	Tensile Stress Lbs./Sq In.	Authority	Date
		VERDE ANTIQUE (Fine veining)				
800	Flat	0.97x2.24	4	2,280	Author	1933
772	"	0.96x2.20	5	2,855	"	"
		GEORGIA WHITE MARBLE				
?	11 to bed	?	?	1290-1395	U.S.Bureau of Standards	1919
?	1 to bed	?	?	1364-1412	" "	"
368	Flat	1.32x1.50	6	1,309	Author	1933
158	"	1.25x1.40	6	606	"	"
380	"	1.00x2.00	6	1,710	"	"
560	"	1.22x1.48	4	1,530	"	"
520	"	1.22x1.48	4	1,418	"	"
460	"	1.40x1.55	7	1,590	"	"
		ETOWAH PINK MARBLE				
?	11 to bed	?	?	885-1567	U.S.Bureau of Standards	1919
?	1 to bed	?	?	1433-1606	" "	"
418	Flat	1.00x2.00	6	1,461	Author	1933
		CREOLE MARBLE				
?	11 to bed	?	?	624	U.S.Bureau of Standards	1919
?	1 to bed	?	?	1320-1536	" "	"
292	Flat	1.00x2.00	6	1,461	Author	1933
		GEROGIA TRAVERTINE (MARL)				
160	Flat	0.70x2.20	6	1,340	Author	1933
82	"	0.74x2.15	6	548	"	"
244	"	0.70x2.24	4	1,332	"	"
196	"	0.75x2.15	4	975	"	"

A SUMMARY OF RESULTS ON TRANSVERSE STRENGTH

Load Lbs.	Loading Position	Section Ins.	Span Ins,	Tensile Stress Lbs/Sq.In.	Authority	Date
		ROCKMART GREY SLATE				
?	Flat	Ave. of 2 tests	12	7,589	US Bureau of Std's.	1917
80	"	0.245x4.50	12	4,920	Author	1933
70	"	0.245x4.50	12	4,620	"	"
80	"	0.146x4.25	8	10,060	"	1934
		FAIRMONT GREEN SLATE				
108	Flat	0.262 x 4.60	12	6,160	Author	1933
68	"	0.186 x 4.60	12	7,650	"	"
80	"	0.212 x 3.25	8	6,580	"	1934
		ITALIAN TRAVERTINE				
117	Flat	1.00 x 1.30	6	1,620	Author	1933
113	"	1.00 x 2.80	5	605	"	"

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A SUMMARY OF RESULTS ON THE MODULUS OF ELASTICITY

Material	Modulus	Authority	Date
Granite (Ave.)	5,700,000 - 8,200,000	U.S.Bureau of Std's.	
Elberton Pink Granite	3,200,000	Author	1933
Wisconsin Granite	156,000 - 2,070,000	Buckley	
Elberton Blue Granite	3,200,000	Author	1933
Stone Mountain Granite	1,300,000 - 2,300,000	Author	1933
Marble (Ave.)	7,200,000 - 14,500,000	U.S.Bureau of Std's.	
Creole Marble	6,896,500 - 6,896,500	Watertown Arsenal	1894
Creole Marble (Bush Hamm'rd)	1,400,000	Author	1933
Ga.White Marble " "	1,000,000	Author	1933
Ga. White Marble (Sawed)	9,090,900	Watertown Arsenal	1894
Etowah Marble	7,843,100	Watertown Arsenal	1894
Etowah Marble (Bush Hamm'rd)	1,100,000	Author	1933
Cherokee Marble	9,090,100	Watertown Arsenal	1894
Kennesaw Marble	7,547,100	Watertown Arsenal	1894
Serpentine	4,800,000 - 9,600,000	U.S.Bureau of Std's.	
Slate	9,000,000 - 15,000,000	U.S.Bureau of Std's.	
Fairmont Green Slate (T)	4,750,000 - 8,600,000	Author	1933
Rockmart Grey Slate (T)	6,100,000	Author	1933

(T) Modulus as determined from flexural stresses transversely loaded.

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OTHER TESTS

HARDNESS

Although Hardness is a test that is very seldom run on building stones, it was judged of value to this report inasmuch as it was not feasible to run the standard impact tests. Wherever the material being tested is homogenous there is a definite relationship between resistance to impact and hardness. However, on account of insufficient data being available at this time no exact value can be given for this relationship other than that the hardness value seems to be the reciprocal of the impact value within certain limits.

The apparatus used for determining the hardness was the Sceleroscope. This piece of apparatus is ordinarily used to determine the hardness of metals by measuring the height of rebound of a diamond pointed pellet after falling freely from a fixed height. This rebound height being the hardness number. The following table is an average value obtained from seven tests:

Etowah Marble	49.6	Dawn Grey Granite	78.1
Creole Marble	47.8	Sunset Pink Granite	76.1
Ga. White Marble	50.6	Long Blue Granite	89.7
Coarse Serpentine	51.4	Stone Mt. Granite	78.6
Fine Serpentine	68.2	Rockmart Slate	52.0
Georgia Marl	27.0	Fairmont Slate	56.0
Roman Travertine	28.0		

For comparative purposes the following are given:

Plate Glass	103.5	Bakelite	86.5
Cast Iron(Grey)	46.0	Steel(High Carbon)	49.0
Steel(Low Carbon)	27.0	Brass(Yellow)	26.2

Fig. 1. Scelerscope. Used for determining the approximate Modulus of Elasticity on Steels.

Fig. 2. From left to right at back. White Marble after being heated to around 500°, White Marble after being heated to 1700° F. and slaking in the air for five days, fresh sample of White Marble. Fresh sample of Serpentine, Serpentine after being heated to 1700° F. and slaking in the air for five days. Front, fresh sample of Italian Travertine,after being heated to 1700° F. and slaking in the air for five days.

Fig. 3. Stone Mt. Granite. Left to right, fresh sample, after being heated to 500°F. and after being heated to 1700° F.

Fig. 4. Elberton Blue Granite. Left to right after being heated to 1700° F. to 500° F. and fresh sample. Sunset Pink Granite after being heated to 1700° F. after being heated to 500° F. and fresh sample.

Fig. 5. Results of compression tests on Long Blue Granite, White Marble, Stone Mt. Granite. Illustrating that materials of relative low compressive value fail in a double cone or pyramid, and those of high compressive values in a single form neither conical nor pyramidal in shape.

PLATE IX

Fig. 1

Fig. 2

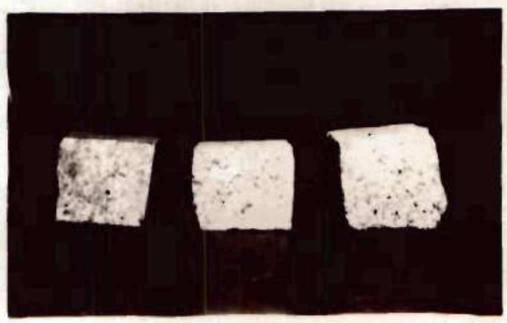

Fig. 3

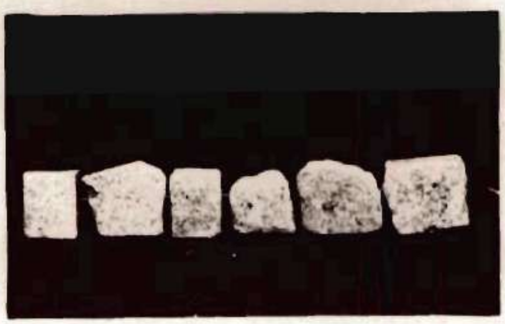

Fig. 4

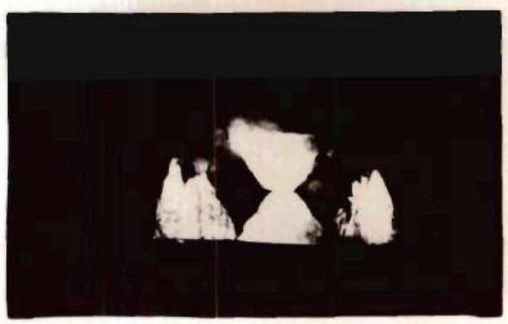

Fig. 5

EFFECTS OF HEAT

Although this is a test that has very seldom been conducted, the value of the results obtained more than justify the time and labor expended in conducting the tests. Various samples of stone were place in an electric furnace in which the temperature was 500° F. They were kept at this temperature for four hours and then quenched in cold water. This procedure was followed as it was desired to see the effects on the structure of the stone caused by expansion and then sudden contraction. In no case was there noted any spalling or failing of the stone except for very small particles being lost by the Stone Mountain Granite and from the vein material in the Serpentine. With the marble tested there was some surface calcination where the $CaCO_3$ had been reduced to CaO and the stone as a whole took on a dull flat appearance. The Elberton Granites showed no effects other than a slight leaching in color which was also evident with the Stone Mountain Granite.

Other samples of the various stones were then weighed for their dry weight and placed in an electric furnace in which the temperature was 1700° F. where they were kept for three hours and fifteen minutes. On removal they were weighed and any losses recorded. The condition of all of the stones showed considerable change. The marbles had a chalky appearance, and likewise the travertines; the Elberton Granites were several shades lighter in color but showed no indications of having spalled except on one speciman where a crack developed on one corner. On the Serpentine there was a decided change notably in color. The mass of the material, originally a dark green in color, took on a red-brown color. Along the veins were observed small checks but no spalling to amount to anything. The Stone Mountain Granite also underwent a marked change. The surface became extremely crumbly, resembling the surface of a sandstone and the muscovite mica changed to a very pronounced golden hue. Also the specimen had the feel and ring usually associated with a high refractory brick.

Although on removal from the furnace all specimen showed apparently little or no change in body structure an examination of the same specimen five days later showed the following: the travertine had collapsed to a billowy white mass (CaO) which fell into a powder at the slightest touch. The marbles had, likewise, collapsed to form a powdery mass about a small center core of dull looking crystals. The serpentine still retained its red-brown color but had collapsed into a granular form. There was no observable change in the Elberton granites, and none in the Stone Mountain granite other than a tendency to flake off easily. An examination three months later showed these conditions to still be prevalent with no change from the fifth day observations.

The following table gives the per cent loss on the gravimetric basis for the various stones tested. The exceptionally high values for the marbles and travertine being due to the loss of water of crystallization when the $CaCO_3$ was reduced to CaO.

Material	Per Cent Loss in Weight
Stone Mt. Granite	0.600
Sunset Pink Granite	0.580
Long Blue Granite	0.320
Dawn Grey Granite	0.225
Ga. White Marble	30.200
Roman Travertine	43.000
Serpentine	20.600

It is of interest to note that when subject to high temperature muscovite mica undergoes a hydra-thermal change which imparts to it a very distinct golden color. Hitherto before this mica was mistaken for granules of gold and could not be explained except that it seemed to be associated with igneous contacts of secondary origin. It was recognized as mica by geologists, but was thought to be biotite. However, these heat tests prove conclusively that it is the muscovite variety as the biotite present in none of the specimen tested showed any color change. As to whether there is any change of chemical composition has not yet been determined but there probably is.

ABSORPTION

By absorption is meant that amount of water that a stone will absorb in a given period of time. The stones tested were dried at a temperature of 220° F. for four hours and then weighed. After becoming completely cool, they were immersed in water and allowed to stand for 48 hours before they were removed. The surface moisture was then wiped off with a towel and the specimen immediately weighed. The gain in weight giving the per cent absorption when substituted in the formula $\frac{(B - A)100}{A}$ where A and B are the two respective weights.

This factor generally gives some idea as to the porosity of the stone and hence its weathering qualities. However, a stone with fine pore spaces will absorb water more slowly than one with coarse pores and also allow it to penetrate farther due to capillary action. Likewise, a stone with coarse pores will lose its water much faster than one with fine pores with the result that on the gravimetric basis this test is not entirely representative for all classes of stone for the same periods of immersion.

The following table gives the results as obtained on the stones under consideration:

Dawn Grey Granite	.355%	Long Blue Granite	.236%
Sunset Pink Granite	.231	Stone Mt. Granite	.175
Roman Travertine	1.290	Serpentine	.655
Ga. Travertine	.772	Ga. White Marble	.1565
Etwah Marble	.1295	Creole Marble	.1630

TRUE SPECIFIC GRAVITY

The true specific gravity may be defined as the unit weight of the mineral constituents of the stone. It is the weight when all of the pores of the stone have been eliminated.

For the determination the stone is ground to a fine powder and that part which will pass a 200 mesh screen is used. The actual determination is made with a specific gravity bottle with a ground stopper having a single perforation. The weight of the bottle dry and full of water is determined, and then the weight of the bottle and some amount of the powdered stone is taken. Sufficient water is then added to completely fill the bottle. The water and powdered stone being intimately mixed to insure the removal of all air, and the weight of this mixture is recorded. Since the powdered stone displaces a volume of water equal to its own, the specific gravity can be computed using the formula that $G = \frac{W}{Z}$ where W is the weight of the stone used, Z is the weight of the water displaced by the stone and is equal to the weight of bottle of water less Y, where Y is equal to the weight of the bottle with the mixture of stone and water less W.

The following table gives the results as obtained on various Georgia stones under consideration:

Georgia Travertine	2.518	Etowah Marble	2.635
Long Blue Granite	2.636	Creole Marble	2.685
Dawn Grey Granite	2.632	Ga. White Marble	2.714
Stone Mt. Granite	2.665	Serpentine	2.545

APPARENT SPECIFIC GRAVITY

The apparent specific gravity is the ratio of the dry weight of a material to the weight of an equal volume of water. The only difficulty involved in this determination is that of obtaining accurately the volume of the specimen. This is done by weighing the specimen dry and then weighing it suspended in water. The difference in the two weights in grams is equal to the volume of the specimen in cubic centimeters. However, in making this test on porous materials one has to prevent the specimen from absorbing while being weighed in water. This is done by determining the volume of the specimen in a more or less saturated condition and requires the taking of three sets of weights; namely, the dry weight in air, the weight after being immersed in water for at least 48 hours, and the weight suspended in water in the saturated condition. The apparent specific gravity is then calculated using the formula that $G = \frac{W_1}{W_2 - W_3}$ which weights are those mentioned above.

This test is of value in computing the porosity of a stone as well as in determining the weight per cubic foot of the material.

The following table gives the values as computed for the Georgia Building Stones under consideration, and *for comparative purposes* will be found values as computed by the Bureau of Standards for the various stones.

Georgia Travertine	2.51	Etowah Marble	2.715
Long Blue Granite	2.635	Creole Marble	2.705
Dawn Grey Granite	2.63	Ga. White Marble	2.709
Stone Mt. Granite	2.65	Serpentine	2.655

Bureau of Standards

Basalt	2.9 - 3.2	Slate	2.6 - 2.8
Soapstone	2.9 - 3.0	Serpentine	2.5 - 2.84
Gneiss	2.7 - 3.0	Granite	2.6 - 2.7
Marble	2.7 - 2.86	Sandstone	2.2 - 2.7
		Limestone	1.87- 2.69

WEIGHT PER CUBIC FOOT

The weight per cubic foot is often needed in computing shipping cost and other data relative to the handling of stone as well as being of value in design work. This value is computed by taking the apparent specific gravity of the material and multiplying it by the weight of a cubic foot of water, 62.4 pounds, as the specific gravity is the ratio of the density of the material to that of the water.

The following table gives the results on the stones tested:

Dawn Grey Granite	164.0	Ga. Travertine	156.5
Long Blue Granite	164.5	Roman Travertine	152.0
Sunset Pink Granite	163.4	Ga. White Marble	168.8
Stone Mt. Granite	165.2	Creole Marble	168.6
Serpentine	165.0	Etowah Marble	169.0

POROSITY

By porosity is meant the amount of pore space or voids occurring in the material. This can be calculated when both the apparent and the true specific gravity are known from the formula that $P = \frac{100(t - a)}{t}$ where the value "t" is the true specific gravity and "a" is the apparent specific gravity.

The porosity is of interest in considering the probable weathering qualities of the stone. In a way it limits the absorption that can take place. Many authorities have assumed that a stone when nine-tenths saturated will rupture if exposed to frost action. This is based on the conclusion that water expands one-tenth of its volume on freezing, and if there is not sufficient area to allow this expansion there will be a disruption of the stone as the expanding force will be greater than the cohesive force.

The following table gives the results as calculated, along with a comparative table compiled by the Bureau of Standards.

Georgia Travertine	.318%	Stone Mt. Granite	.56%
Long Blue Granite	.0379%	Ga. White Marble	.184%
Dawn Grey Granite	.076%		

By Bureau of Standards

Diabase	0.2 - 1.2%	Quartzite	1.5 - 2.9%
Granite	0.3 - 2.6%	Sandstone	1.9 - 22.0%
Marble	0.4 - 1.8%		

From the comparative table it would appear that the author's results are out of line, and this is further confirmed by the fact that in the case of all the marbles tested the true specific gravity gave a value less than the apparent which automatically gave a negative porosity factor. These stones were rechecked with utmost care and there was found to be no change in relative results. The only explanation that seems in the least feasible is that ordinary tap H_2O was used, and that there were sufficient impurities present to throw the specific gravity results off or else some dissolved chlorine attacked the specimen. The latter seems to have some merit inasmuch as only the calcite rocks were extremely out of line. The igneous rocks which would be inert to such action all gave positive results. A check test run using distilled H_2O gave positive results indicating this was evidently the error.

DISCOLORATION

By the term discoloration is meant any change from natural color other than that caused by surface deposits of soot or grime which are apt to collect on any building. The kinds of discoloration that may occur are: local stains caused by the absorption of extraneous matter from other parts of the building, or that carried into the stone by ground water; the alteration of certain minerals on being exposed to the weather, and impurities in the stone which become leached to the surface by percolating waters.

Although it was once thought that many discolorations found on stones were due to impurities in the mortar used for bonding, it has been conclusively proved by the work of Sligh and Kessler[1] of the Bureau of Standards that the oxidation or alteration of these impurities in the mortar has practically no affect on the stone. Their tests also showed that different waters used in the mortar had nothing to do with the discoloring of a stone. One conclusion that they did reach though was that water in percolating through the mortar becomes slightly alkaline which makes it more absorbent, and as a result, organic material on the surface of the stone will more readily be taken into solution by the water and result

1. Physical Properties of Limestones, Sligh and Kessler; p. 530

in a stain on the masonary. Their conclusions were that most of the staining was due to the walls being uncovered while under construction. An examination of jobs where the walls had been covered while under construction showed far less staining than jobs where this had not been done.

Other discolorations due to the stone itself vary. After prolonged weathering most stones change in appearance. Biotite granites are apt to stain in brown and yellow splotches due to the alteration of the biotite. Granites having large feldspar crystals are apt to take on a dull white, clayey look due to the alteration of the feldspar to the secondary mineral, kaolin. Serpentine, particularly the Georgia variety, takes on a gray cast after weathering for a while. The marbles lose their luster as the acid-laden rain water attacks the calcite crystals. These processes are naturaland cannot well be prevented.

Other discolorations such as that caused by gases, soot-laden air, oil, and various cleansing agents, so called, take place in a much shorter period of time than the natural phenomena and in the majority of cases completely overshadow those discolorations due to mineral alteration.

EFFECTS OF WEATHERING

Although there are many artificial tests that have been used for testing the weathering properties of various stones, it was decided not to use these after corresponding with the Bureau of Standards[1]. Quoting their communication, "In regard to the chemical effect of rain water or atmosphere exposures, a fairly definite measure of this action can be obtained by experimenting with cubes or small slabs with rounded edges. These may be dried and carefully weighed and then exposed to the weather for a few months. Where there is a normal rainfall a measurable loss will occur in a short period of time."

Through the cooperation of the local office of the weather Bureau in Atlanta, specimen of the various Georgia Stones under consideration were exposed from the observatory of that Bureau on the top of Citizens and Southern Bank Building in Atlanta from October 28, 1933 to March 20, 1934.

The following table shows the per cent loss on the gravimetric basis for an average of 3 tests.

Dawn Grey Granite	0.0857	Ga. White Marble	0.133
Long Blue Granite	0.033	Verde Antique	(+)0.1397
Sunset Pink Granite	0.0357	Ga. Travertine	0.124
Stone Mt. Granite	0.0486	Roman Travertine	0.261

1. Bureau of Standards to G.P. Woollard, Dwk:SLB, file Ix-9/Irsu.

It will be noted that the Verde Antique showed a gain in weight. As all 3 specimen showed this phenomena, it can only be concluded that some chemical reaction took place which caused an increase in density which more than offset the erosive effects of weathering.

The balance of the results were what might be expected. The travertine showing the greatest loss due to their perforated structure and calcium carbonate base, the marbles next and the granites last. This shows rather conclusively that the weathering action was mostly chemical rather than mechanical.

An examination of the meteorological summary sheets for the period of exposure gave the following averages:

Humidity (per cent)	65.8
Temperature (Average° F.)	22.0 - 74
Temperature (Extreme° F.)	7.0 - 86
Rainfall (To normal)	-1.4
Hail	2
Light Frost	9
Killing Frost	9
Snow or Sleet	7
Thunderstorms	9

Fig. 1. Panarama view of part of the specimen tested.

Fig. 2. Transverse specimen tested.

Fig. 3. Samples after being weathered naturally for four and a half months.

Fig. 4. Specimen after 132 freezing cycles.

Fig. 5. Some of the specimen after tested after failure.

PLATE X

Fig.1

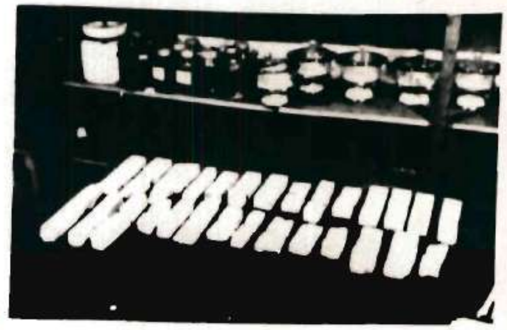

Fig.2

Fig.3

Fig.4

Fig.5

FREEZING TESTS

Different investigators have used different methods in investigating the effects of freezing on the various stones tested. Most of these tests have been on the way freezing affects the ultimate compressive strength of the stone. However, as no conclusions could be reached on this as on one stone it caused an increase and on another a corresponding decrease in strength, the author was led to approach the subject from another angle. As all previous tests had called for from 20 to 40 freezing cycles, it was decided to run a series of freezing cycles of at least a 100 and as many more as conditions permitted, and rather than test for any changes in strength to test for losses in material. Realizing that no exact duplication of the freezing cycles of nature could be obtained in the short period of time in which this work was to be conducted, a test method had to be devised that would permit artificial operation and yet at the same time approximate actual conditions. As most previous tests had been with specimen in a more or less saturated condition which is not a condition met with actually, it was decided to run the tests with the stone holding no more water than would be the case for the prevailing humidity. The stones were first dried out at 200^{o} F. for two hours and exposed for three days to current conditions with the humidity about 55%. They were then placed in a cold chamber and carried down to 16^{o} F. for 12 hours. At the end of this period they were exposed to prevailing conditions for 12 hours and the cycle repeated. One hundred and thirty-two cycles were run in all and then the specimen were dried as originally and weighed. Since these tests were run the author has received a copy of the work of Sligh and Kessler of the Bureau of Standards on the Commercial Limestones of the United States. In their investigation of this problem on limestone they used a method based on the same conclusions as the author. However, they ran tests to destruction and used a higher degree of saturation. In thawing the specimen they ran regular tap water on them, and also they ran three cycles daily which not only gave a higher amount of water in the pore spaces but also gave more rapid reversal of stresses. They found that with some limestones they got complete failure in less than a 100 cycles and with others they did not get failure with 1800 cycles. However, as a measurable loss occurred with the tests as conducted on Georgia Stone some idea as to the relative qualities of the various building stones tested is gained from the following table. The table is an average loss for four tests.

Verde Antique	.1461%	Dawn Grey Granite	.0485%*.0301
Italian Travertine	.0215	Stone Mt. Granite	.1273
Long Blue Granite	.0495	Ga. White Marble	.0313
Sunset Pink Granite	.0378	Ga. Travertine	.0739

*Ave. of 3 as one value was extremely out of line.

A SUMMARY OF TESTS ON GEORGIA STONES

Material	Compressive Strength Lbs/Sq.In.		Transverse Strength Lbs/Sq.In.	Modulus of Elasticity	Hardness	Specific Gravity	
	Bed	Grain				True	Apparent
Stone Mt.Granite	25,862	15,443	1,644	2,300,000	78.6	2.665	2.65
Long Blue Granite	25,348	18,750	2,900	3,200,000	89.1	2.636	2.635
Dawn Grey Granite		17,533	2,586	3,200,000	78.1	2.632	2.63
Sun Set Pink Granite		17,533	2,586	3,200,000	76.1	2.632	2.63
Lithonia Granite	28,970	18,500					2.686
Ga. White Marble	10,828	8,825 *	1,511	9,090,900	50.6	2.714	2.709
Etowah Marble	12,020	8,694 *	1,622	7,843,100	49.6	2.635 '	2.715
Creole Marble	12,550	10,750 *	1,439	6,896,500	47.8	2.685 '	2.705
Cherokee Marble	10,150		1,279	9,090,900			2.708
Mezzotont Marble	11,800		1,500				2.716
Amicalola Marble	10,685		1,580				2.726
Verde Antique							
(coarse)	3,457		1,163		51.4	2.545 '	2.655
(fine)			2,550		68.2		
Georgia Travertine	3,366		1,049		27,0	2.518	2.51
Roman Travertine	4,851		1,112		28.0	2.518	2.43
Rockmart Slate			6,797	6,650,000	52.0		
Fairmont Green Slate			6,796	6,640,000	56.0		

* - Bush hammered specimen.
' - Values probablly in error.

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A SUMMARY OF TESTS ON GEORGIA STONES

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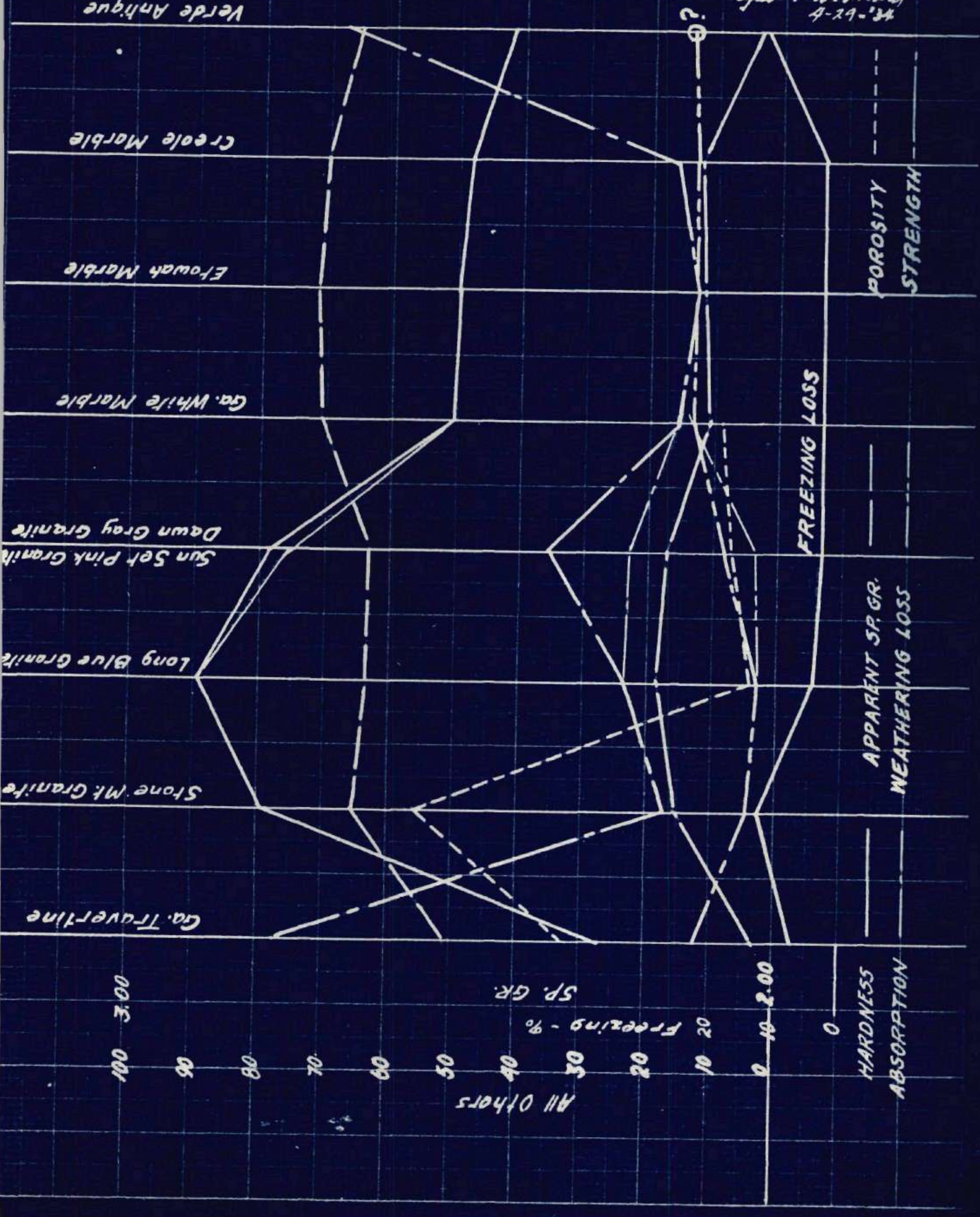
* - Bush hammered specimen.
' - Values probablly in error.

TESTS RELATIONSHIPS

Geo. P. Woollard
4-29-'34



DISCUSSION OF CURVES

From the curves plotted for the different qualities of the various stones tested it is seen that there is a definite relationship between compressive strength and hardness. This has long been known to exist in metals, and by knowing the hardness of steel it is possible to compute not only the modulus of elasticity of the material but also the per cent carbon present without further testing. The results of the present tests indicate that there is a similar relationship present in rocks. Although the hardness and the strength seem to vary more or less directly, no conclusions can be definitely stated at this time beyond approximations. An examination of the curves plotted for the mineral constituents of the granite under consideration shows that for the three granites tested the strength seems to vary inversely as the amount of quartz present and directly with the Alumina (Al_2O_3) present. As to the effects that the presence of the minerals have on the strength nothing can be concluded at this time other than the stated relationships seem to exist.

As stated earlier in this report the compressive strength could not be taken as a guage of the durability, and this fact is borne out when the curves for weathering and freezing losses are compared with the strength curve. In a general way the losses due to freezing or mechanical agents vary directly with the per cent porosity. The losses occasioned by weathering appear to be more the results of chemical agents rather than mechanical ones and seem to vary roughly with the specific gravity and to a certain extent inversely with the hardness.

An examination of the two curves for absorption and porosity bears out the conclusions previously stated under the discussion of results of absorption tests. Off hand it would appear that these two qualities would vary more or less directly with each other. However, the data plotted indicates that there is an inverse agreement which is explained on the ground that a stone having a high absorption would have coarse pores and lose its water quickly while one with low absorption would have fine pores that would hold water longer due to capillary action which explains the fact that these stones having a high percentage of porosity suffered the greatest losses when frozen.

CONCLUSIONS

Strength:

All of the various stones tested showed more than sufficient strength to meet any requirements that might be demanded of them for contruction purposes.

Hardness:

All of the stones tested showed a hardness equal to or greater than a low carbon steel, and in general it can be stated that the strength varies more or less directly with the hardness.

Porosity:

The porosity is indicative of the mechanical losses that might be expected from freezing and bears an inverse rather than a direct relationship to absorption.

Absorption:

The absorption is not a guage of the losses that might be expected from freezing except when considered as the reciprocal.

Apparent Specific Gravity:

The results obtained check very closely with those of previous investigators, and showed the densities of the stones tested to vary in the following order: (1) marble, (2) serpentine, (3) granite and (4) travertine.

Specific Gravity:

The results obtained are logical and indicate clearly the voids existing in the consolidated stone which are not accounted for in determining the apparent specific gravity.

Weathering:

The losses due to weathering appear to be predominantly chemical rather than mechanical, and seem to vary directly with the apparent specific gravity.

Freezing:

The freezing losses which are mechanical, apparently vary directly with the porosity and inversely with the absorption.

High Temperatures:

Most of the stones tested will stand temperatures up to 500° Fahrenheit without serious injury other than a dulling of finish. However, when taken to temperatures as high as 1700° Fahrenheit all of the stones are practically destroyed.

CONCLUSIONS ON THESIS

Additional work of a more extensive nature should be done on the relations between strength, hardness and mineral constituents to determine the exact relations which appear to exist. Such an investigation would require work and time beyond the scope of a Master's Thesis as well as considerable funds for the preparation of specimen needed.

Other work that should receive further consideration is the relationship between porosity, absorption and freezing losses. The freezing tests as conducted, it is believed, give results comparable with natural conditions.

Respectfully submitted

[illegible signature]

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